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2019

TA-8910 NEP: Earthquake Emergency Assistance Project

Prepared for Asian Development Bank

UET

FINAL REPORT ON SHAKING TABLE TESTING

TA-8910 NEP: Earthquake Emergency Assistance Project
Experimental Verification of Remote School Type Designs

May 2019

Prepared for Asian Development Bank (ADB)

Katmandu, Nepal.

This experimental verification program was undertaken with the generous support by the Government of the People's Republic of China.

TA-8910 NEP:
EARTHQUAKE EMERGENCY ASSISTANCE PROJECT

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ACRONYMS

ASTM	American Society for Testing and Materials
ADB	Asian Development Bank
CSM	Cement Stabilized Mortar
CoV	Coefficient of Variation
CSEB	Cement Stabilized Earth Brick
EEAP	Earthquake Emergency Assistance Project
EW	East-West
FE	Finite Element Model
F	Free Vibration
GI	Galvanized Iron
IP	In Plane
IS	Indian Standard
IAEE	International Association of Earthquake Engineering
RILUM LUM	International Union of Laboratories and Experts in Construction Materials, Systems and Structures
Ksi	Kilo pound per square inch
kN	Kilo Newtons
KIRT	Kirtipur, time history record
Mpa	Mega Pascal
M	Meters
Mm	Millimeter
MOE	Ministry of Education
MCE	Maximum Considered Earthquake
NBC	Nepal National Building Code
N	Newtons
OOP	Out-of-Plane
PGA	Peak Ground Acceleration
Psi	Pound per square inch
PSD	Power Spectral Density
CLPIU	Project Implementation Unit at the Central Level
RC	Reinforced Concrete
RSA	Response Spectrum Analysis
SM	Semi-dressed Stone Masonry
SAP2000	Structural Analysis Program, CSI Inc.
TA	Technical Assistance
TORs	Terms of References
3D	Three Dimensional
USM	Unstabilized Mortar
UTM	Universal Testing Machine
UET	University of Engineering and Technology, Peshawar
URM	Unreinforced Masonry
W1	Wall 1 (Front Wall)
W2	Wall 2 (Back Wall)
W3	Wall 3 (Side Wall)
W4	Wall 4 (Side Wall)
WWM	Welded Wire Mesh

NOTATIONS

G	Gravitational acceleration
A_s	Area of steel
f_c'	Compressive strength
Sa/g	Design acceleration coefficient, obtained from the response spectra IS1893
V_s	Design base shear force
A_h	Design horizontal seismic coefficient
f_{tu}	Diagonal tension strength
E_d	Dissipated energy per cycle
$R\mu$	Ductility factor
D	Effective depth
V_e	Elastic base shear force
L_g	Gauge length
Z	Damping ratio
V_y	Idealized yield strength
I	Importance factor
τ_0	In-plane shear strength
E_i	Input stored energy.
E	Modulus of elasticity
M_n	Nominal moment capacity
R_S	Overstrength factor
Δ_{d1}	Recorded deformation in horizontal diagonal
Δ_{d2}	Recorded deformation in vertical diagonal
R	Response modification factor
W	Structural weight
Z	Seismic zoning factor
V_c	Shear capacity
θ	Shear deformability
T	Time period
A	Whitney stress block depth
B	Width of band
f_y	Yield strength

KNOWLEDGE SUMMARY

Shake Table tests were conducted on following four Type Designs:

- Type Design 1 (SM_RC): Semi-dressed stone masonry in cement stabilized mud mortar with reinforced concrete (RC) band, splints and Galvanized Iron (GI) containment mesh on wall surfaces.
- Type Design 2 (SM_Gabion): Semi-dressed stone masonry in mud mortar with GI gabion band and containment mesh on wall surfaces.
- Type Design 3 (CSEB_RC): Cement stabilized earth brick (CSEB) in cement stabilized mud mortar with RC bands and vertical bars at wall junctions and jambs.
- Type Design 4 (SM_Timber): Semi-dressed stone masonry in mud mortar with timber bands and GI containment mesh on wall surfaces.

The test models of all Type Designs 1, 2, 3 and 4, were subjected to sinusoidal and seismic excitations with moderate to high levels of peak ground acceleration, ranging up to 1.0g. The models in almost all cases suffered damages but without partial or total collapse of walls and without triggering any unstable mode of failures indicating the overall satisfactory performance of the models. The reason for avoiding collapse in case of stone masonry models was the effectiveness of horizontal bands coupled with surface containment. The good behavior of CSEB model was due to the provision of horizontal bands and vertical re-bars at wall corners and jambs.

Following is the knowledge summary of the investigation:

- If low strength masonry (LSM) building and its components could maintain integrity, and volume, the loss of lives could be prevented. LSM buildings could survive very strong shaking due to sliding and rocking of masonry distributed along bedding planes, limiting shaking of the building system by cutting down the seismic force.

- The current building standards are not sufficient to address issues of LSM buildings as these have been basically developed for reinforced concrete and steel-based constructions, hence, the current codal provisions cannot be applied to LSM buildings in entirety.
- Reinforced concrete and steel frame structures dissipate seismic energy through few plastic hinges, formed at the beam-column members during seismic excitation. But, the seismic energy from LSM buildings is released from the building system through distributed cracks in the walls, significantly larger than the conventional systems, whereby the system control demand on structures. This makes LSM buildings far more efficient from energy release point of view.
- Strength capacity, i.e. minimum base shear capacity of LSM buildings cannot be the sole criteria for understanding or evaluating performance of LSM buildings.
- Strength capacity of LSM buildings cannot be enhanced substantially like concrete and steel buildings, which is because of the limitations imposed by the mortar and/ or masonry units.
- If LSM buildings and their components could maintain integrity, these could deform substantially, thereby can survive very strong shaking.
- The LSM buildings may apparently have low base shear capacity, but unlike concrete and steel-based construction, initial damping starts contributing at the early stages of response. Seismic codes suggest 5% elastic damped response spectra for design that inherently simulate the elastic damping of system, however, initial damping up to 10% has been observed for the strengthened masonry during the shake table testing, that helped in reducing the seismic forces.

EXECUTIVE SUMMARY

This report presents the results of various tests conducted on four “one-room, single- story” reduced scale masonry models: one Cement Stabilized Earth Brick Masonry (CSEB) and three Stone Masonry (SM) models. The experimental investigation was conducted under TA-8910 NEP: Earthquake Emergency Assistance Project funded by the Asian Development Bank (ADB). The preliminary design of these four Type Designs was carried out by the design specialist Engr. Jitendra Bothara. In order to evaluate the seismic performance of the proposed designs through a comprehensive experimental program, the ADB engaged Prof. Dr. Qaisar Ali and Asst. Prof. Dr. Naveed Ahmad of Civil Engineering Department (CED), University of Engineering and Technology Peshawar, Pakistan (UETP). The Central Level Project Implementation Unit-Education (CLPIU-Edu) under National Reconstruction Authority, Government of Nepal intends to use these designs, after verification of their compliance to Nepal Building Code, for construction/reconstruction of schools in remote areas of Nepal because construction of schools in those remote areas using modern material e.g. reinforced concrete or steel, is considered to be very costly and logistically challenging.

The design specialist proposed the following four Type Designs:

- Type Design 1 (SM_RC): Semi-dressed stone masonry in cement stabilized mud mortar with reinforced concrete (RC) band, splints and Galvanized Iron (GI) containment mesh on wall surfaces.
- Type Design 2 (SM_Gabion): Semi-dressed stone masonry in mud mortar with GI gabion band and containment mesh on wall surfaces.
- Type Design 3 (CSEB_RC): Cement stabilized earth brick (CSEB) in cement stabilized mud mortar with RC bands and vertical bars at wall junctions and jambs.
- Type Design 4 (SM_Timber): Semi-dressed stone masonry in mud mortar with timber bands and GI containment mesh on wall surfaces.

A comprehensive set of materials and subassembly tests were carried out to acquire various structural properties. Compression and diagonal tension tests were conducted on masonry samples for all representative models to determine their various properties, as reported in Table ES1 and ES 2, respectively.

Table ES 1: Basic mechanical properties of stone and CSEB masonry prisms

Mechanical Properties	**Stone Prisms in Cement Stabilized Mud Mortar (1:1:10) ***	**Stone Prisms in Mud Mortar**	**Stone Prisms without mortar**	**Stone Prisms in Mud Mortar with wire containment**	**CSEB in cement stabilized mud mortar**
Compressive Strength, fc' (MPa)	2.30	2.59	1.93	2.62	1.40
Modulus of Elasticity, E (MPa)	81.17	151.09	39.39	75	153.59

*Cement: Sand: Soil

Table ES 2: Mechanical properties obtained from diagonal compression test

S. No	**Description**	**Stone Wallettes in mud mortar without containment (One Specimen)**	**Stone Wallettes in Mud Mortar with containment (Avg. of Four Specimens)**	**CSEB Wallettes in stabilized mud mortar (Avg. of Three Specimens)**
1	**Diagonal Tensile Strength (MPa)**	0.07	0.082	0.034
2	**Shear Strength (MPa)**	0.10	0.115	0.047
3	**Modulus of Rigidity, G (MPa)**	4.08	3.26	34.82

In-plane quasi-static cyclic tests were conducted in order to obtain in-plane response parameters of wall piers for all four representative masonry models, as reported in Table ES 3.

Table ES 3: Masonry wall in-plane response parameters

S. No	Description	Stone Masonry in Unstabilized Mud Mortar with containment	CSEB in stabilized mud mortar
1	**In-plane Lateral Strength, kN**	12.26	9.0
2	**Yield Drift (%)**	0.37	0.09
3	**Ultimate Drift (%)**	2.90	0.81
4	**Ductility Ratio**	7.80	8.26
5	**Damping at Yielding (%)**	18.33	37.5
6	**R-Factor (pier)**	3.82	4.91
7	**R-Factor (wall)***	2.65	2.89

*R-factor$_{(wall)}$ has been calculated from R-factor$_{(pier)}$ using standard relationship available in the literature (Seismic Vulnerability of Buildings, Kristin Leng)

Furthermore, as part of the project, eight shake table tests were also conducted on reduced scale models (two tests for each representative prototype; one reduced to 2/3rd and other reduced to 1/3rd scale of the prototype). The reason for testing two models was that the Asian Development Bank required the models not to be scaled down than 1/2 of the prototype and that the models shall be subjected to acceleration time history. Although, a shake table of the size (6m x 6m) was available at UET Peshawar, which could accommodate a 2/3rd test model, the table presently (at the time of testing, June-2018) was capable of producing only sinusoidal excitation. However, another shake table of the size (1.5m x 1.5m) was also available at UET Peshawar, which could produce desired seismic excitation but could not accommodate more than 1/3rd reduced scale model. Consequently, it was agreed between the UET team and the Asian Development Bank after several sessions of discussions that two models, one 2/3rd scale and another 1/3rd scale, should be tested. The 2/3rd reduced scale models were subjected to sinusoidal excitations of multiple frequencies varied between 2 Hz to 12 Hz and base displacements varying from 1.5mm to maximum, producing moderate-to-strong acceleration base excitations up to 1.0g. Moreover, the 1/3rd reduced scale models were subjected to acceleration time history of the Northridge 1994 earthquake record, compatible with 5% damped elastic acceleration spectrum (India Standard IS: 1893), linearly scaled from 5% to 240% (that is equivalent to 1.0 g). The 1/3rd scale models of Type Design 2, 3 and 4 were also subjected to KIRT_EW. The KIRT_EW time history was recorded at Kirtipur, Kathmandu on a rock site from the 25 April 2015 Gorkha earthquake and was used as supplementary test. Consequently, the shake table tests were conducted according to the aforementioned methodology. The experimental data obtained from both the tests was used for plotting the force-deformation capacity curves, as shown in Figure ES 1.

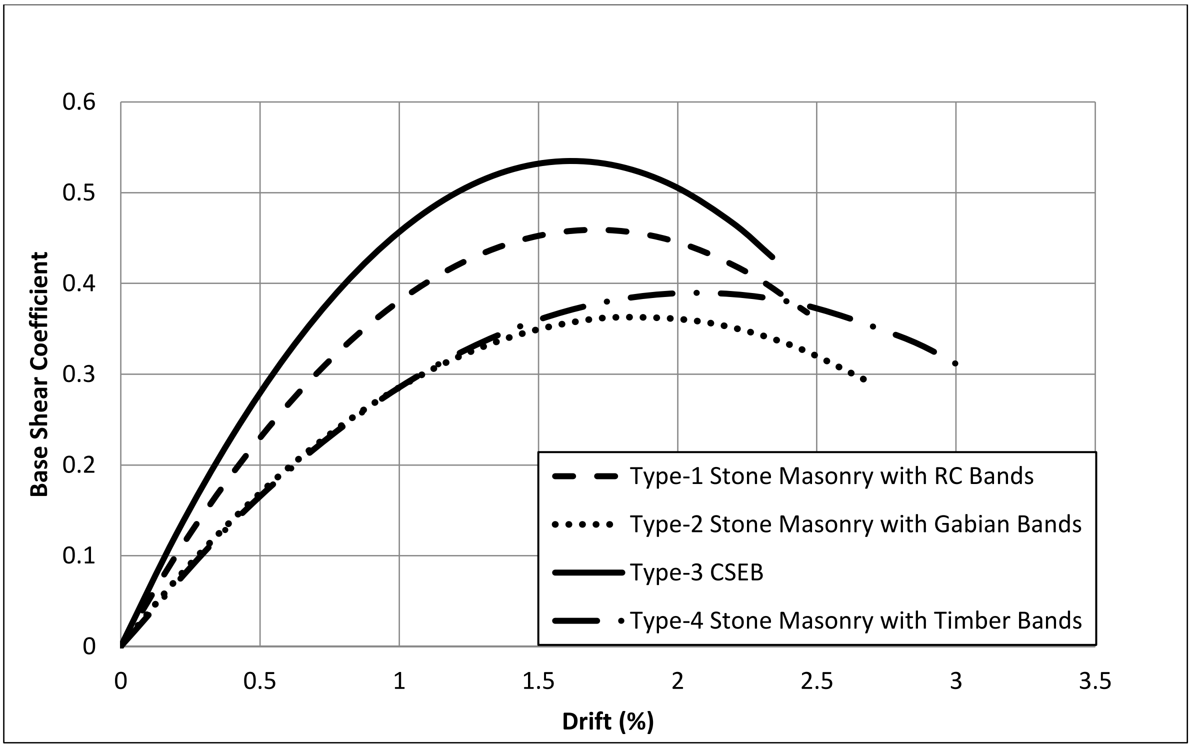


Figure ES 1: Combined Capacity Curves of all four Type Designs

To understand performance of cosmetically repaired models, the 1/3rd scale Type Design 2 and 3, and 2/3rd scale Type Design 3 were also tested on the shake table after cosmetic repair and were subjected to the same test protocol to which the virgin models were subjected to including KIRT_EW time history. Similar to the tests of the virgin models, these models were tested in the transverse direction. Following, testing of the repaired 1/3rd scale Type Design 3 model, it was also tested in the longitudinal direction without any further repair. The 1/3rd scale Type Design 1, 2 and 4 were also re-tested after removal of 50% and 100% containment wires from the wall surfaces. The force-deformation capacity curves were bi-linearized as elasto-plastic curves to obtain the response modification factor (R-Factor), reported in Table ES 4. The combined bi-linear idealized capacity curves are shown in Figure ES 2.

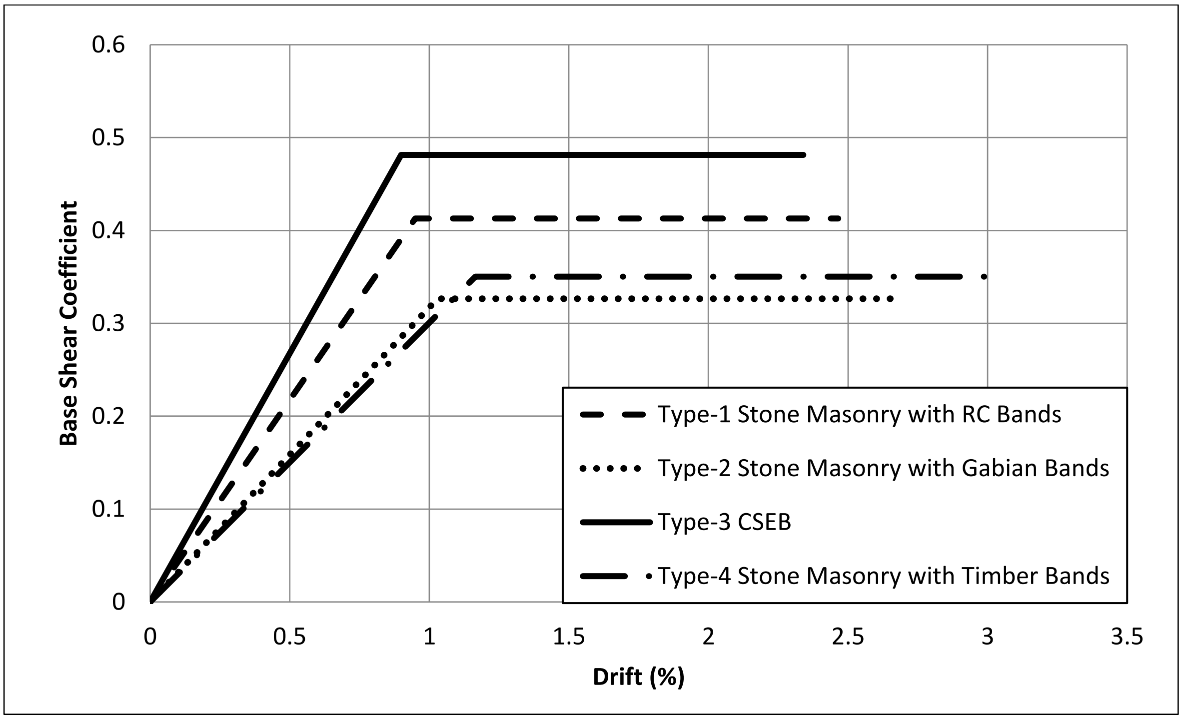


Figure ES 2: Combined bi-linear idealized Capacity Curves of all four Type Designs

Table ES 4: Response modification factors of all fourType Desigs

Type Design	R-Factor of the Structures from Shake Table Tests
Type Design -1 Stone Masonry with RC Bands	2.60
Type Design -2 Stone Masonry with Gabion Bands	2.61
Type Design -3 CSEB with RC Bands	2.60
Type Design -4 Stone Masonry with Timber Bands	2.58

Note: The force-deformation plots that were derived for development of R-factor was constrained close to 2.5% drift because of limited data available, despite the models survived much higher drift limits. Had the higher drift limits were accounted for, that would have resulted in higher R factors. However, R-Factors of 2.50 has been recommended for all Type Designs.

The experimental investigation has shown that all stone masonry models (Type Design – 1, 2 and 4) were capable to resist strong excitations up to 1.0g, without triggering any unstable mode of failures, except plaster spalling and fall of a few small stones from walls. A lack of trigger of any unstable mode of failure, even at drift much higher than 2.50%, confirms that the structures still have more reserve capacity to resist earthquake shaking. Under very extreme shaking, the model showed significant sliding and rocking of stones in the in-plane wall panels, due to in-plane forces and induced lateral displacement. At very extreme shaking the out-of-plane walls also rocked severely. However, the containment wires played a re-centering role and the wall panels were observed with no significant distress (permanent deformation). Both sliding and rocking failures are generally regarded as efficient energy release mechanisms. This confirms that the design schemes were capable to resist severe earthquake shaking without any collapse or major damage that could endanger the occupant's lives during the design level earthquake event. Depending upon the band types, models either responded in the in-plane mode (Type Design 1) or out-of-plane modes (Type Design 2 and Type Design 4).

The walls after removal of containment mesh were observed with significant loss of stone units, however, walls with 50% containment mesh were observed with falling of few stone units from the walls, yet maintaining strength and integrity.

Both models of the Type Design - 3 were capable to resist moderate-to-strong excitations, without triggering any unstable mode of failures, except fall of few brick units and damage to corner of walls and toe crushing of buttress at drift of 2.50%. Nevertheless, the vertical elements and bands were able to avoid total or partial structural collapse and were able to provide stability to structure for carrying gravity loads after the end of shaking. This confirms that the design scheme is capable to resist design level earthquake shaking without serious structural collapse that could endanger the occupants' lives during the earthquake event. To further increase the structural performance, an additional intervention (e.g. containment wire or similar like) will be beneficial to contain brick units after sliding out. This can avoid fall of brick units during shaking that, in turn, will ensure safety of occupants. This Type Design primarily responded in the in-plane mode.

The seismic design codes typically provide 5% damped elastic design spectrum for calculating seismic forces. It is worth mentioning that up to 10% initial damping was observed, which has also been confirmed during similar tests conducted by other studies (Benedetti et al, 1998) on masonry in weak mortar. This indicates that the code specified design spectra shall not be extended directly to considered structures for seismic design, but rather, the design spectra can be reduced to represent the actual elastic damping of the structure. Similarly, the final damping up to 20-30% were observed in each Type Design.

Attempts were made to define seismic performance levels as Immediate Occupancy Level (IO), Life Safety Level (LS) and Collapse Prevention Level (CP), as defined by the FEMA 273 (1997) guidelines for seismic rehabilitation of buildings. For this, the drift corresponding to 20% drop in the base shear force of structure was assumed as the CP limit state; the LS limit state drift has been taken as 75% of the CP level drift; the IO level has been taken as 70% of the idealized yield drift of the structure. The corresponding Base Shear Coefficients (BSC) for each drift limits were calculated from the equation of force-displacement backbone curves. The limit state drifts and base shear coefficients are reported in Table ES 5.

Table ES 5: Performance Levels of all Type Designs

Type Design	Parameters	Immediate Occupancy (I.O)	Life Safety (L.S)	Collapse Prevention (C.P)
Type Design-1	**Drift (%)**	0.67	1.85	2.47
	BSC	0.29	0.46	0.37
Type Design-2	**Drift (%)**	0.72	2.02	2.69
	BSC	0.23	0.36	0.29
Type Design-3	**Drift (%)**	0.63	1.76	2.34
	BSC	0.34	0.53	0.43
Type Design-4	**Drift (%)**	0.82	2.25	3.00
	BSC	0.25	0.39	0.31

In order to examine the usability of all four Type Designs in various seismic zones of Indian Standard IS: 1893-2016, performance-based assessment of structures was carried out. The demand base shear coefficient (A_h) for each zone was compared with the experimental base shear coefficient (BSC_e), in order to evaluate the seismic performance of structures in each seismic zone. The BSC_e was taken equal to the life safety BSC. Seismic performance of each Type Design in various zones is shown in Table ES 6.

The experimental testing program, and the following-up analysis completed at the University of Engineering and Technology (UET), indicates that the proposed Type Designs are compliant to the Nepal Building Code (NBC) and are expected to survive very severe earthquake shaking likely in the Zone V of the Indian seismic standard IS-1893-2016.

Table ES 6: Seismic performance in various seismic zones (Indian IS:1893-2016)

Type Design	**Zone**	**Level of Seismic Hazard**	**Zone Factor - Z**	**Demand BSC** (5% damping) Ah = (Z x I x Sa)/ (2 x R x g) *L. F**	**Demand BSC** (8% damping)**	**BSCe**	**Seismic Performance**
Type Design -1	II	Low	0.1	0.11	0.09	0.46	**OK**
	III	Moderate	0.16	0.18	0.14		**OK**
	IV	Severe	0.24	0.27	0.23		**OK**
	V	Very Severe	0.36	0.41	0.33		**OK**
Type Design -2	II	Low	0.1	0.11	0.09	0.36	**OK**
	III	Moderate	0.16	0.18	0.14		**OK**
	IV	Severe	0.24	0.27	0.22		**OK**
	V	Very Severe	0.36	0.41	0.33		**OK**
Type Design -3	II	Low	0.1	0.11	0.09	0.53	**OK**
	III	Moderate	0.16	0.18	0.14		**OK**
	IV	Severe	0.24	0.27	0.22		**OK**
	V	Very Severe	0.36	0.41	0.33		**OK**
Type Design -4	II	Low	0.1	0.11	0.09	0.39	**OK**
	III	Moderate	0.16	0.18	0.14		**OK**
	IV	Severe	0.24	0.27	0.22		**OK**
	V	Very Severe	0.36	0.41	0.33		**OK**

** Based on calculated R-factor

CHAPTER 1: INTRODUCTION

1.1 Background

The Central Level Project Implementation Unit under National Reconstruction Authority, established after the 25th April 2015, Gorkha earthquake, is responsible for the execution and implementation of Earthquake Emergency Assistance Project (EEAP) on schools. The Asian Development Bank (ADB) provided financial support to the CLPIU for construction/reconstruction of school buildings in the earthquake-affected areas of Nepal. This investigation for design of school buildings employing locally available materials has been undertaken under a Technical Assistance Grant from the ADB. With the goal of maximum use of locally available materials and minimum use of imported materials, the design specialist Engr. Jitendra Bothara proposed the following four Type Designs:

- Type Design 1 (SM_RC): Semi-dressed stone masonry in cement stabilized mud mortar with reinforced concrete (RC) band, splints and Galvanized Iron (GI) containment mesh on wall surfaces.
- Type Design 2 (SM_Gabion): Semi-dressed stone masonry in mud mortar with GI gabion band and containment mesh on wall surfaces.
- Type Design 3 (CSEB_RC): Cement stabilized earth brick (CSEB) in cement stabilized mud mortar with RC bands and vertical bars at wall junctions and jambs.
- Type Design 4 (SM_Timber): Semi-dressed stone masonry in mud mortar with timber bands and GI containment mesh on wall surfaces.

The ADB engaged UET Peshawar, Pakistan through TA-8910 NEP: Earthquake Emergency Assistance Project for seismic performance verification of above mentioned four Type Designs models through an extensive experimental program.

1.2 Objectives of the Project

The core objectives of the assignment “TA-8910 NEP: Earthquake Emergency Assistance Project - Experimental Verification of Remote School Type Designs (49215-001)” primarily includes:

- To test scaled-models of one-room buildings representing the Type Designs to simulated earthquake shaking on a shake table.
- Understand the model’s dynamic properties, seismic behavior, damage pattern, etc.
- Provide necessary material testing, and complete calculations and numerical simulations prior to the shake table tests.

1.3 Scope of the Project

The laboratory experimental program included the following tests:

- Experimental tests on constituent materials and subassemblies (stone/CSEB units, prisms, wallettes, walls/piers) for the mechanical characterization of building construction materials.
- Shake table testing on 2/3rd and 1/3rd scaled one-room representative models of all the four Type Designs, proposed by the design specialist.
- Test data analysis and calculation of resistance against earthquake forces.

1.4 Report Organization

Chapter 1 presents the general background, objective and scope of the project. Chapter 2 reports description of the proposed prototype configurations. Chapter 3 presents the numerical modeling of prototype of test models and design of structural components for seismic actions. Chapter 4 summarizes the basic tests carried out on constituent materials and sub-assemblages and reports the experimentally obtained mechanical properties of masonry. Chapter 5 summarizes the shake table tests conducted on all test models (both 2/3rd and 1/3rd) and describes the observed behavior of test models. Chapter 6 elaborate on the seismic performance of test models and reports the basic seismic response parameters. Chapter 7 reports the conclusions derived based on the experimental studies.

CHAPTER 2: DESCRIPTION OF PROPOSED DESIGNS

2.1 General Configuration and Details

The design specialist proposed four Type Designs, for typical two-rooms and three-rooms, single-story masonry school buildings, as shown in Fig 1 and Fig. 2. These Type Designs were proposed to provide guidelines for construction/reconstruction of school buildings in remote earthquake affected areas of Nepal. These proposed Type Designs primarily use local materials like clay and stones, which are abundantly available in these remote areas. Keeping in mind the observed behavior of low strength masonry in past earthquakes, the proposed four Type Designs were provisioned with seismic interventions to improve their seismic behavior. The general description and detailing of each Type Design are presented as follows. However, minor modifications were made to the configuration of buildings before construction of test models. A few of these are: 1) Thickness of all stone masonry walls were changed to 400mm thick, 2) Thickness of all CSEB walls were changed to 380mm, 3) GI mesh grid changed to 200mmx200mm, 4) Interbedded geogrids were not used for any Type Design. All stone masonry models were provided with buttresses to both long and short walls, however, to understand behavior of buttress, these were only provided to one long and one short walls of the Type Design 3.

2.2 Type Design 1 (SM_RC)

This Type Design composed of loadbearing walls was built in semi-dressed stone masonry using cement stabilized mud mortar. The walls in this Type Design were provided with RC bands at sill, lintel and eave levels (Fig. 3). Surface containment prepared of galvanized Iron (GI) wire mesh is also applied on both the interior and exterior surfaces of walls, to avoid falling of stones. The surface containments were connected through cross ties placed in the masonry courses at regular intervals. Furthermore, RC splints were also provided at the wall junctions of building for strengthening purposes (Fig. 4). Interbedded GI mesh stitches were also provided in walls at corners and wall junctions in masonry panel at mid-height between plinth and sill level and sill and lintel levels to strengthen wall junction connections. Further information regarding the preliminary geometric dimensions and structural detailing are shown in Appendix A1.

2.3 Type Design 2 (SM_Gabion)

Similar to Type Design 1, this Type Design was also composed of load bearing walls built in semi-dressed stone masonry but mud mortar. However, instead of RC bands, the walls in this Type Design were provided with gabion bands at sill, lintel and eave levels (Fig. 5). Similarly, surface containment prepared of GI wire mesh was also applied on both the interior and exterior surfaces of walls. The surface containments were connected through cross ties placed in the masonry courses at regular intervals. Furthermore, interbedded GI mesh stitches were also provided in walls at corners and wall junctions in masonry panel at mid-height between plinth and sill level and sill and lintel levels (Fig. 6). Corners, doors/windows jambs were strengthened with additional vertical wires wrapped around the walls. Further information regarding the preliminary geometric dimensions and structural detailing are shown in Appendix A2.

2.4 Type Design 3 (CSEB_RC)

This Type Design composed of loadbearing walls, was built in cement stabilized earth brick (CSEB) masonry in cement stabilized mud mortar. Unlike the stone masonry buildings, the wall thickness of CSEB masonry is 250 mm which was later changed to 380mm. Consequently, the plan dimensions of CSEB masonry buildings were a little different than the stone masonry buildings (Fig. 7). Similar to Type Design 1, the walls in this Type design were provided with RC bands at sill, lintel and eave levels (Fig. 8). Furthermore, the loadbearing walls were reinforced with vertical re-bars at wall junctions and door/window jambs (Fig. 9). The wall junctions were also reinforced with stitches. It is worth mentioning that surface containment was not applied on walls in this Type Design. Further information regarding the preliminary geometric dimensions and structural detailing are shown in Appendix A3.

2.5 Type Design 4 (SM_Timber)

Similar to Type Design 1 and 2, this Type Design was also composed of loadbearing walls built in semi-dressed stone masonry but in mud mortar. However, instead of RC or gabion bands, the walls in this Type Design were provided with timber bands at sill, lintel and eave levels, similar to the timber band proposed in the National Building Code of Nepal (Fig. 10). Similarly, surface containment prepared of GI wire mesh was also applied on both the interior and exterior surfaces of walls. The surface containments were connected through cross ties placed in the masonry courses at regular interval. Furthermore, similar to Type Design 1 and 2, interbedded GI mesh stitches were also provided at junctions in masonry panel at mid-height between plinth and sill level and sill and lintel levels. Wall junctions, doors/window jambs were strengthened with additional vertical wires wrapped around the walls. Further information regarding the preliminary geometric dimensions and structural detailing are shown in Appendix A4.

2.6 Representative Prototype for Test Models

To fulfill the test models scaling requirements, shake table testing of two-rooms or three-rooms model was not possible due to the size and payload capacity limitations of the seismic simulators. Therefore, a representative single-room prototype was proposed for shake table testing, taken out from two-room building with larger rooms considering higher vulnerability. The dimensions and detailing of the prototype were confirmed with the Asian Development Bank. The design of structural components of prototype and the detailing of the test models are discussed further in Chapter 3.

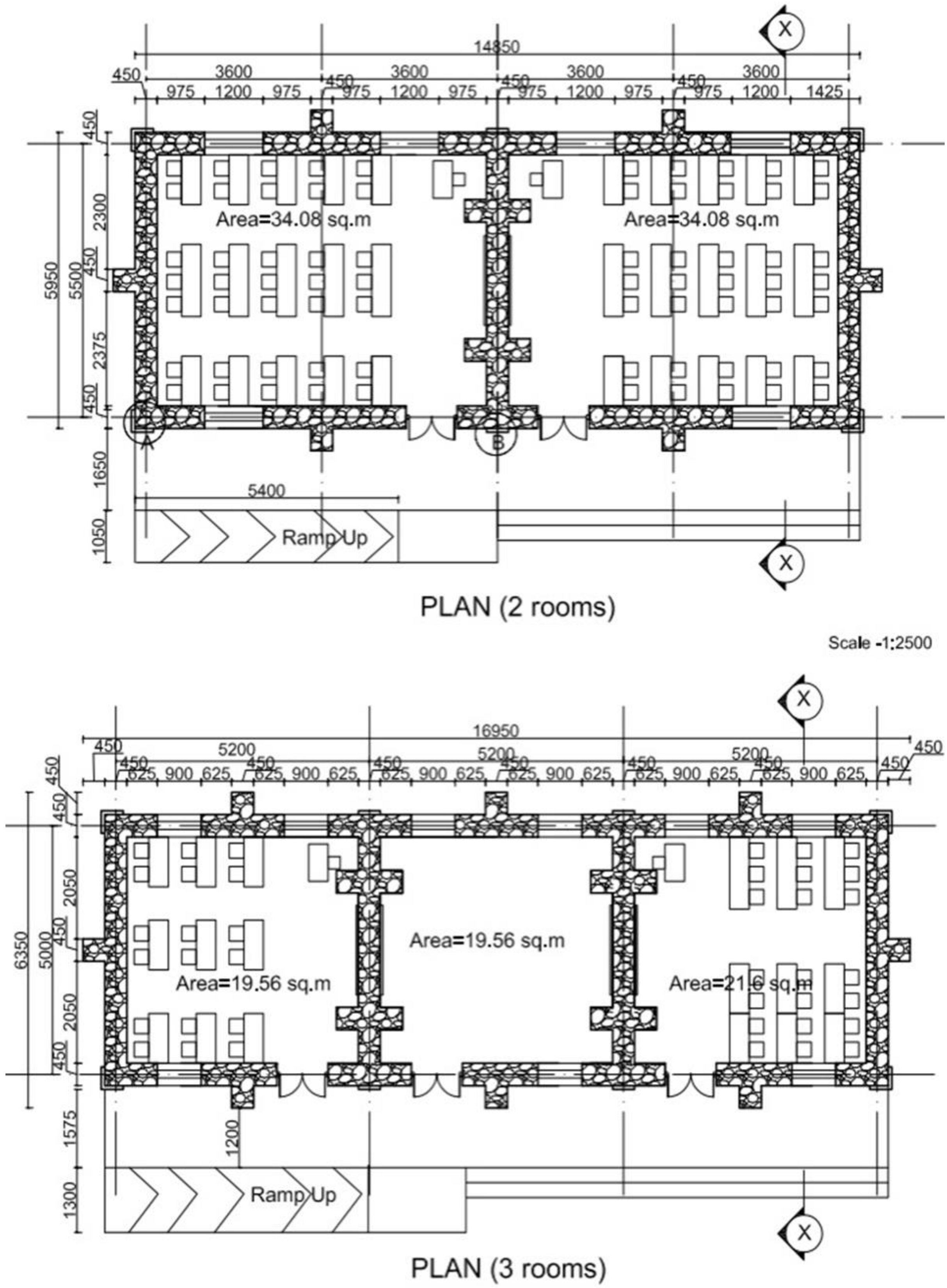


Figure 1: Typical two-rooms and three-rooms building plans for proposed designs (Stone Masonry).

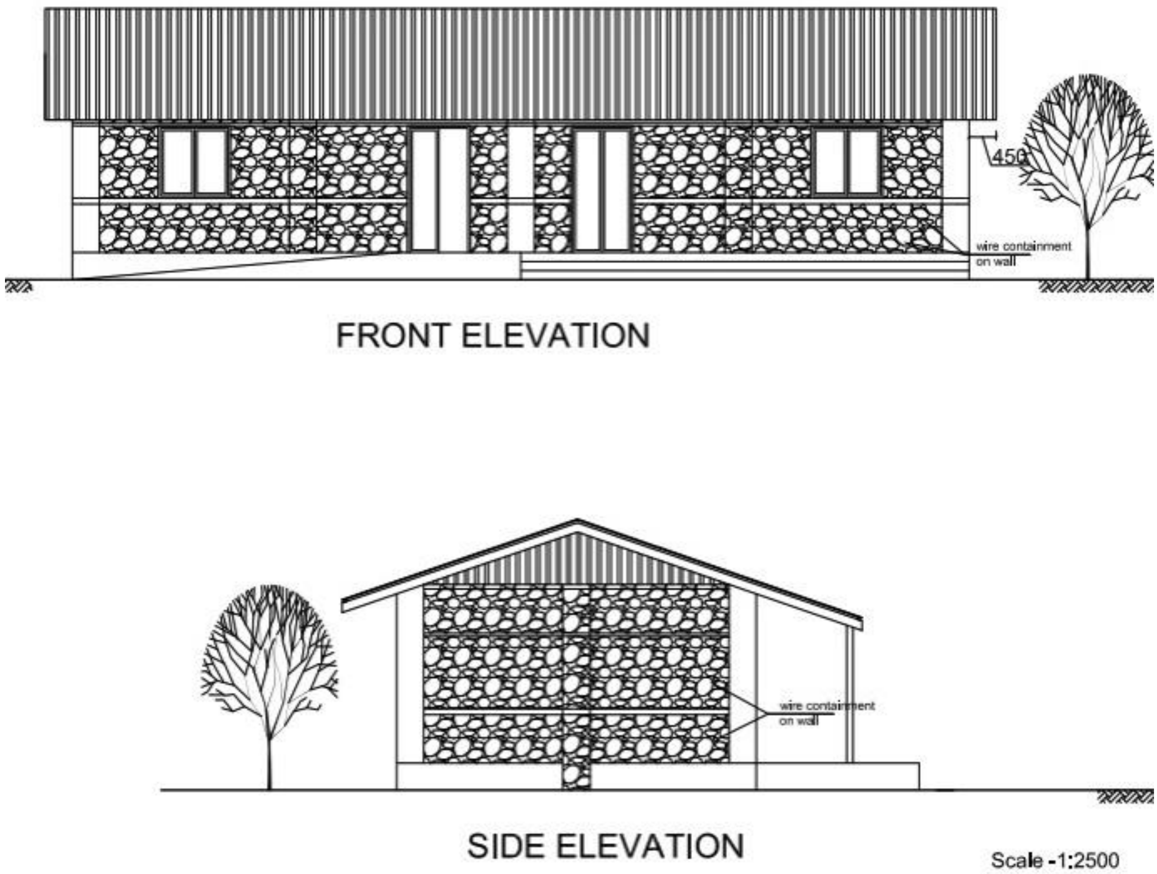


Figure 2: Front and side elevation of the proposed designs

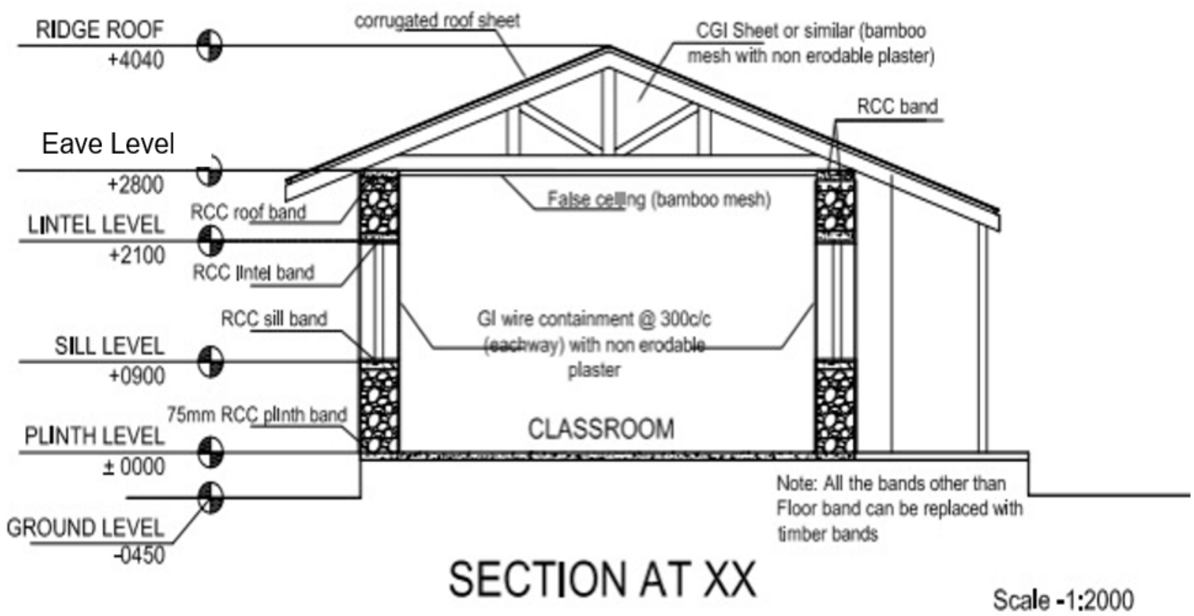


Figure 3: Type Design 1 (SM_RC): Semi-dressed stone masonry in cement stabilized mud mortar with RC band, splints and Galvanized Iron (GI) containment mesh on wall surfaces.

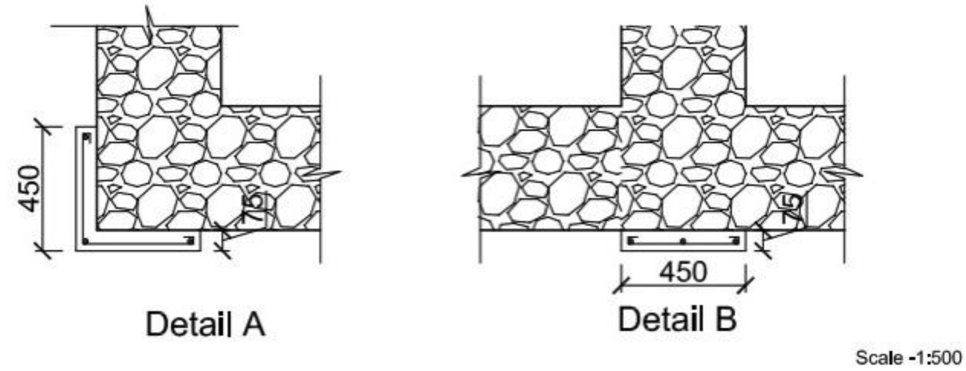


Figure 4: Close-up view of RC splints used in Type Design 1 (SM_RC)

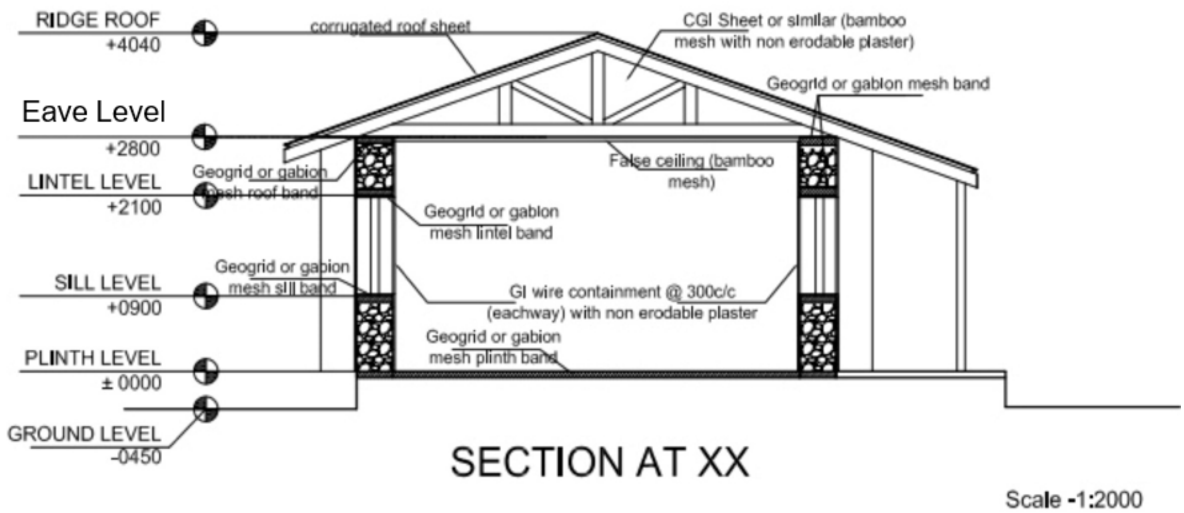


Figure 5: Type Design 2 (SM_Gabion): Semi-dressed stone masonry in mud mortar with GI gabion band and containment mesh on wall surfaces.

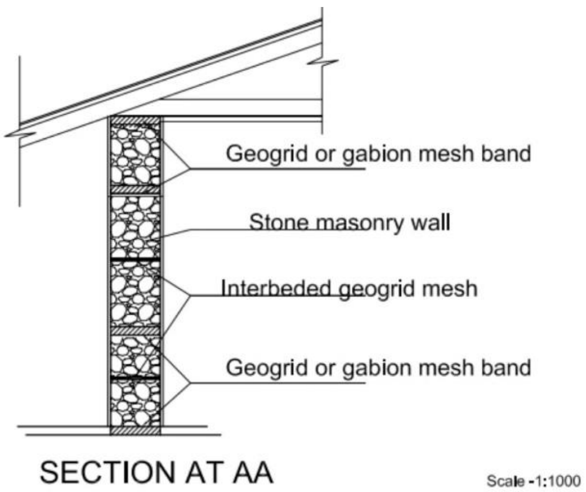
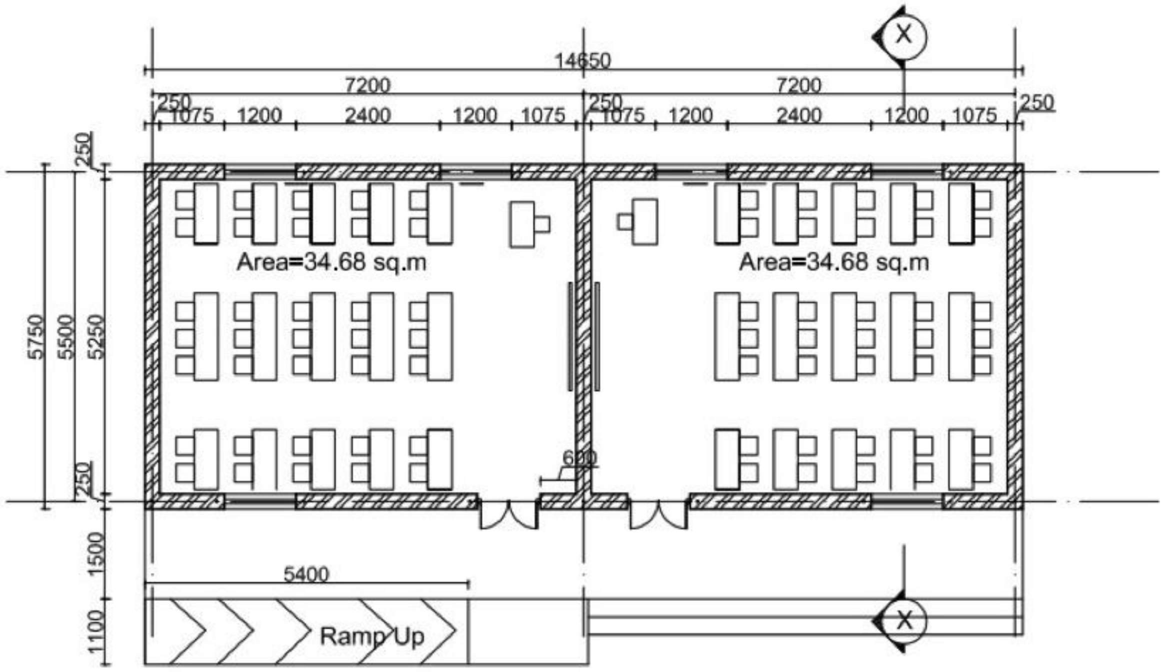
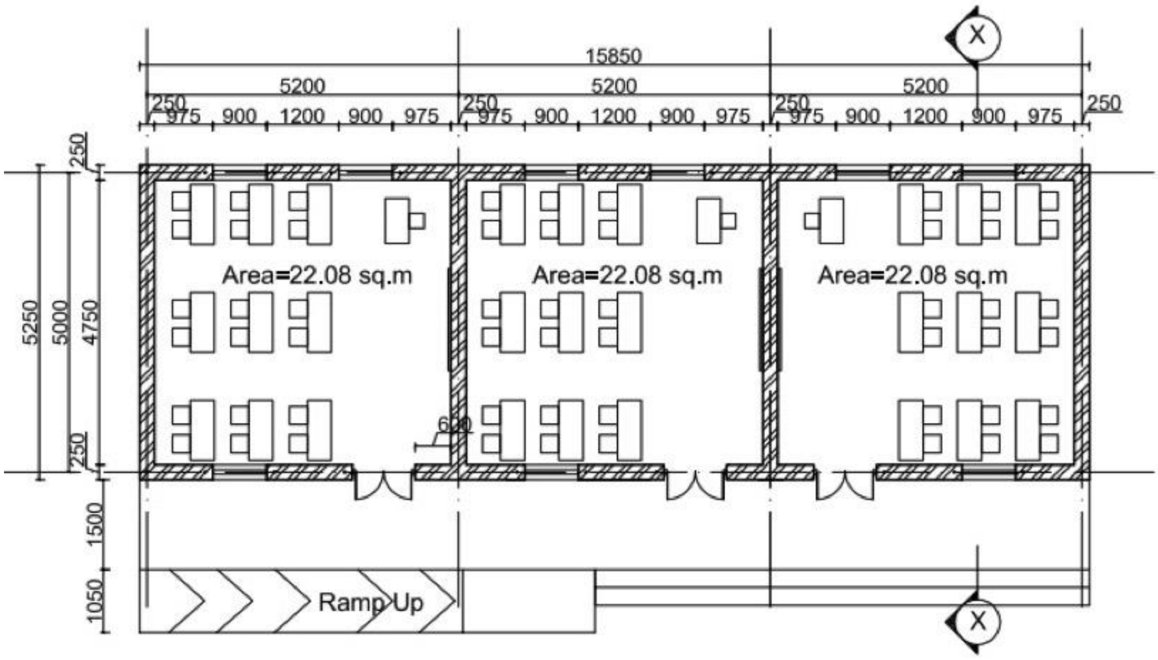


Figure 6: Wall cross-section for Type Design 2 showing placement of Gabion band and interbedded geogrid mesh.



PLAN (2 rooms)

Scale -1:2500



PLAN (3 rooms)

Figure 7: Typical two-rooms and three-rooms building plans for CSEB-RC masonry buildings.

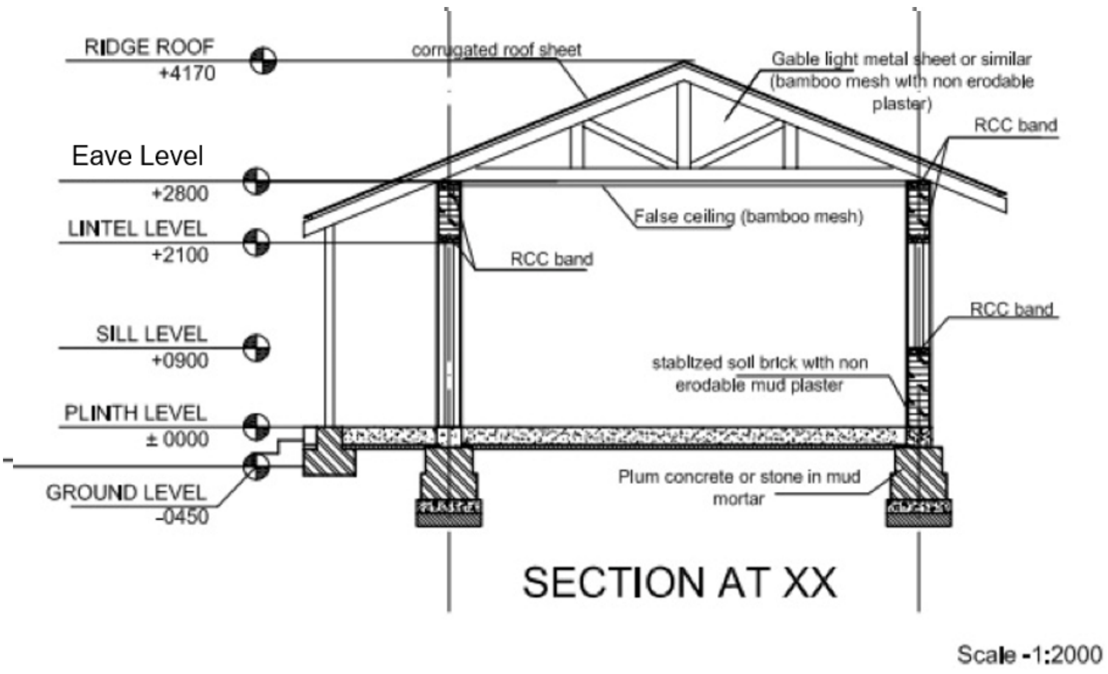


Figure 8: Type Design 3 (CSEB_RC): Cement stabilized earth brick (CSEB) in cement stabilized mud mortar. with RCC bands and vertical bars at wall junctions and jambs

Figure 9: Light reinforcing of walls with vertical re-bars in Type Design 3 (CSEB_RC) (Source: Buildup Nepal).

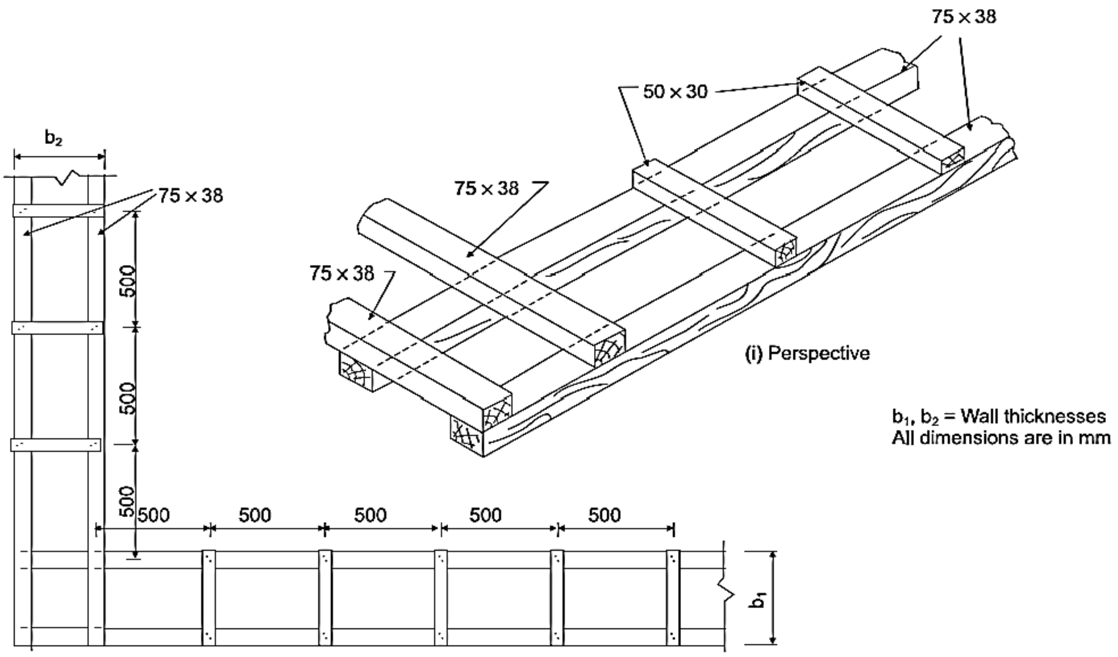


Figure 10: Timber band arrangement proposed in the National Building Code of Nepal.

CHAPTER 3: DESIGN OF PROTOTYPE

3.1 Numerical Modeling of Prototype

For the design of structural components, a 3D finite element based numerical models were prepared for the one room prototype of all Type Designs in SAP2000 (Figure 11). The structural walls and roof sheet were modeled using shell element (shell thin), while roof trusses, purlins, vertical re-bars and bands were modeled using frame elements, which were assigned with the appropriate material and section properties. Table 1, 2 and 3 reports details with regard to member idealization and the considered material and section properties. For modeling of timber and gabion bands, moment releases were considered at the frame elements corner to avoid development of moments at the corners.

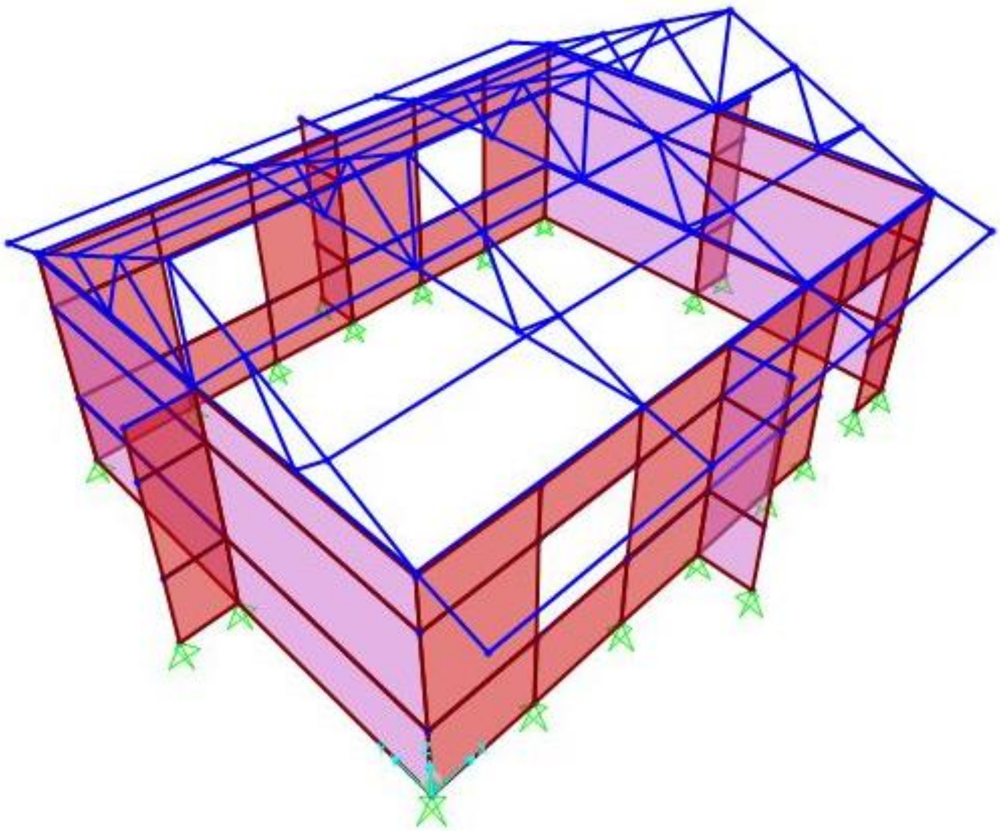


Figure 11: Finite element-based model for complete structure in CSI SAP2000.

Table 1: Material properties considered in the design of stone masonry models (Type 1, 2 and 4)

S. No.	Material Property	Value
1	Compressive strength of stone masonry	2.50 MPa
2	Compressive strength of concrete	10 MPa
3	Modulus of elasticity of stone masonry	75 MPa
4	Poisson ratio of stone masonry	0.15
5	Unit weight of stone masonry	20.42 kN/mm^3
6	Modulus of elasticity of timber truss elements,	3345 MPa
7	Yield strength of galvanized wires	428 MPa

Table 2: Material properties considered in the design of CSEB masonry model (Type 3)

S. No.	Material Property	Value
1	Compressive strength of earth brick masonry	1.4 MPa
2	Modulus of elasticity of earth brick masonry	120 MPa
3	Poisson ratio of earth brick masonry	0.2
4	Unit weight of earth brick masonry	18.85 KN/mm^3
5	Modulus of elasticity of Truss Elements	3345 MPa
6	Compressive strength of concrete	10 MPa
7	Yield strength of re-bars	500 MPa

Table 3: Prototype members idealization and section properties considered in modeling

S. No.	Member ID SAP 2000	Model Type	Element	Type	Material	Size
1	T50x100*	Prototype	Frame Element	Truss Member	Wood	50mm x 100mm
2	T75x75*	Prototype	Frame Element	Truss Member	-do-	75mm x 75mm
3	Stone Wall 400	Prototype	Shell Element	Stone Masonry	Stone	400mm
4	RC Band	Prototype	Frame Element	RC	Concrete	400mmx75mm

5	Gabion Band	Prototype	Frame Element	Stone Masonry	-do-	400mmx200mm
6	Timber Band	Prototype	Frame Element	Runners	Wood	75mmx30mm
7	Timber Band	Prototype	Frame Element	Spacers and Diagonals	Wood	50mmx30mm
8	SWG20	Prototype	Shell Element	GI Sheet	A36	0.914mm
9	CSEB Wall	Prototype	Shell Element	Earth Brick Masonry	Earth Brick	380mm

*: Timber

3.2 Response Spectrum Analysis

The primary loading included the self-weight of the structure and the earthquake load, which was defined through response spectrum functions and assigned with the IS-1893:2016 specified building elastic response spectra. Figure 12 shows the elastic response spectrum generated for the definition of response spectrum functions for the finite element based model. The load combination factor for seismic (1.5) was also considered, as specified in the IS-1893-2016.

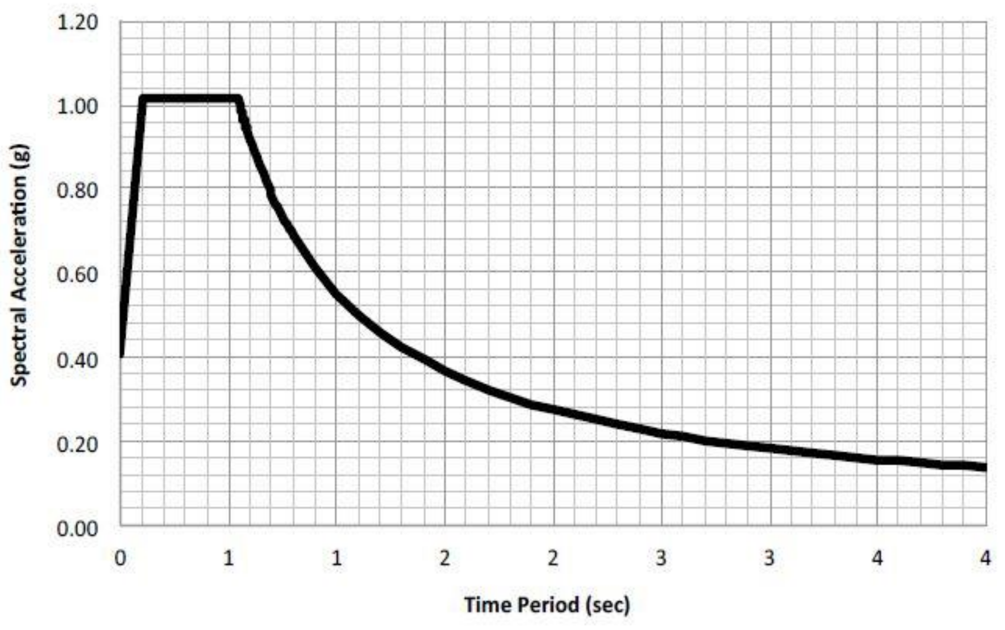


Figure 12: Elastic response spectrum, specified in IS-1893:2016 (Z=0.36, Medium Stiff Soil, Type II)

The IS1893-2016 has specified design horizontal seismic coefficient (A_h) for both the equivalent static and modal response spectrum methods:

$$A_h = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g}$$

The corresponding seismic design base shear at the base of the principal building structure:

$$V_b = A_h W$$

where,

Z: Seismic zoning factor, 0.36 (Zone V, the highest seismic zone, Table 3, IS-1893)

I: Importance factor, 1.5 (school building, Table 8, IS1893)

R: Response reduction factor, refer to the following Table 4, assumed as 2.5, herein

$\frac{S_a}{g}$: Design acceleration coefficient, obtained from the response spectrum

W: Seismic weight of the structure

$A_h = 0.27$

Additionally, the above equation should also include a load factor of 1.5.

Table 4: Force Reduction Factor, R for masonry specified in the IS:1893:2016

Building types	Building System/ Element	Force Reduction Factors R
Unreinforced masonry (designed as per IS1893) with horizontal RC seismic bands and vertical reinforcing bars at wall junctions and jambs of openings (with reinforcements as per IS4326)	In-plane walls	2.5
	Out-of-plane walls	2.5

3.3 Design of Seismic Components

3.3.1 Type Design 1

3.3.1.1 RC Bands

The idea of using RC seismic bands is similar to masonry wall strengthening method; included in the guidelines of Nepali Standards, NBC203 (1994) and appropriate Indian Standards, and has satisfactory behavior in many past Himalayan earthquakes. The typical RC band comprised of two longitudinal reinforcing bars tied through cross ties provided at 150 mm c/c (Figure 13). RC seismic bands were modeled using frame elements with appropriate concrete section.

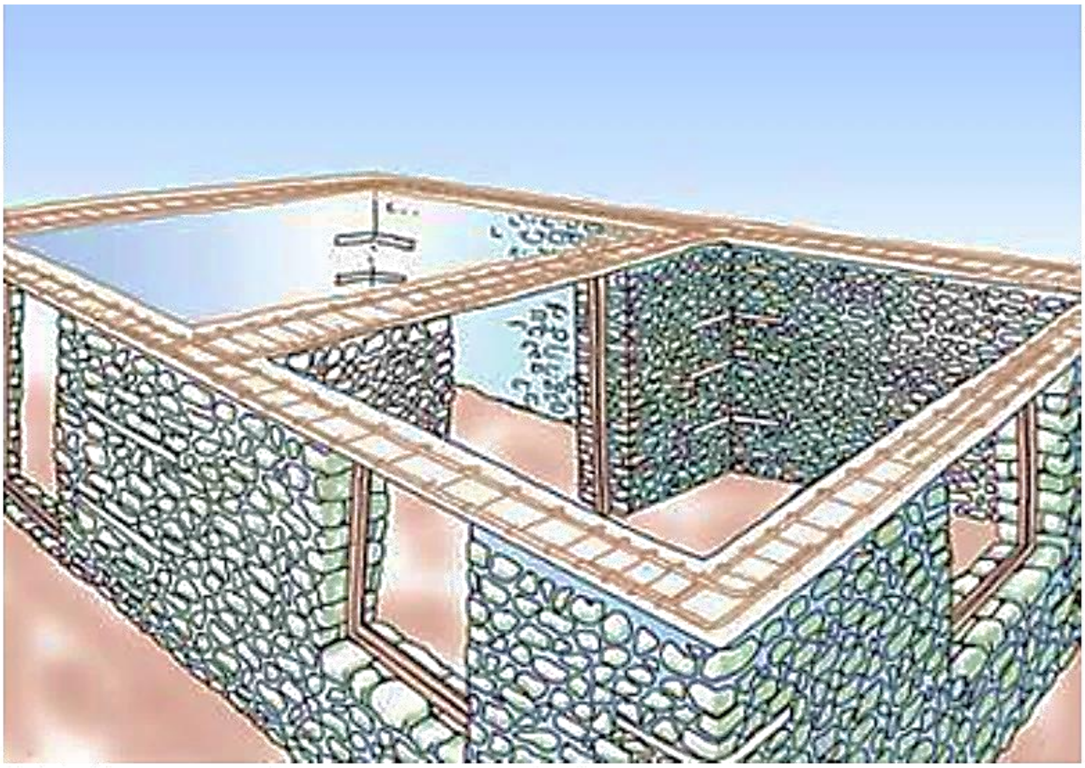


Figure 13: Masonry Wall Strengthening Proposed for Low Strength Masonry (NBC203-1994) (Sketch: NSET)

The numerical model was analyzed and the member tension, shear forces and bending moment were obtained, and the maxima were identified for the bands. The actions obtained were retrieved and processed to compute the tensile, shear and bending stresses in each member, which are compared with the permissible limits. The following provide details of the calculated forces for the RC seismic bands.

Design Calculation for Seismic Analysis Bands

Effective depth of band, d = (400-30) = 370 mm

Width of band, b = 75 mm

Compressive Strength of Stone masonry, fc' = 10 MPa (1.5 ksi)

Yielding strength of steel bar, fy = 500 MPa

Diameter of bar = 16 mm

Area of single bar = 201 mm2

Steel area = 1 x 201 = 201 mm2

Depth of Whitney stress block, a= (As x fy)/ (0.85 fc' b) = 152.75 mm

Nominal Moment Capacity, Mn=As x fy (d-a/2) = 29.571 x106 N-mm = 29571 kN-mm

While the nominal moment capacity of 12mm diameter bar in RC bands at sill level is 18527 kN-mm

Peak Demand on RC Bands from Response Spectrum Analysis:

Table 5: Peak demand on seismic bands at each level, obtained from RSA

Eave Band		Lintel Band		Sill Band	
Moment	**Shear**	**Moment**	**Shear**	**Moment**	**Shear**
(kN-mm)	**kN**	**(kN-mm)**	**KN**	**(kN-mm)**	**kN**
15868	16.3	11260	8.93	5794	4.76

Thus, the nominal moment capacity is greater than the demand on RC bands.

Gravity Analysis for the lintel band above the openings

Flexure Design of RC band

Load from roof = 0.135 kN/m

Load of stone Wall on Lintel band above openings = 4.66 kN/m

Self-weight of Lintel Band above openings = 1.11 kN/m

Factored Load = 1.2*(0.135+4.66+1.11) = 7.1 kN/m

Factored moment = 7.1*1.2^2/9 = 1.28kNm

Depth of RC band = 125 mm

Effective depth of RC band, d = (125-30) = 95 mm

Width of band, b = 400 mm

Compressive Strength of concrete, fc' = 10 MPa (1.5 ksi)

Yielding strength of steel bar, fy = 500 MPa

Diameter of bar = 12mm

Area of single bar =113 mm2

Steel area = 1 x 113 = 113 mm2

Depth of Whitney stress block, a= $\frac{As*fy}{0.85*fc'*b}$ = 17 mm

Nominal Moment Capacity, Mn=As x fy (d-a/2) = 4.88 kN-m

Capacity to Demand ratio = 4.88/1.28 = 3.81

Shear Design of RC band

Shear demand = 8.93 kN

Shear capacity = ØVc =$\frac{Ø*2*\sqrt{fc\prime}*b*d}{1000}$ = 15.4 kN

ØVc/2 = 15.4/2 = 7.7

theoretically no need of web Reinforcement. ("2" is the factor of safety)

3.3.1.2 Splints

Design of Splints

Maximum moment demand on the Splint is 5836 kN-mm. The moment capacity is given below:

Effective depth = (450-30) = 420 mm

Bar diameter = 8 mm

No. of bars = 2

Bar area = 50.24 mm2

Steel area = 100.53 mm2

Yielding strength of bar = 414 MPa

Compressive strength (fm') = 2.5 MPa

Depth of Whitney stress block, a= 400 mm

Nominal Moment Capacity, Mn=As x fy (d-a/2) = 9.15 x106 N-mm = 9150 kN-mm

Thus, the nominal moment capacity is greater than demand on splint.

3.3.1.3 Containment Wires

The design and verification of wire containment mesh included the design of vertical and horizontal steel wires and specification of wires' spacing for application. The demand on wall was computed, as out of plane bending at multiple levels of wall, both vertical and horizontal, through response spectrum analysis of masonry building. The vertical and horizontal bending capacity of wall is calculated using the simple reinforced concrete section analogy that considers wire with tension capacity and stones to provide compression.

Out of Plane Bending Moment Capacity of Wall

Effective depth, d = 400 mm

Width of Wall, b = 1000 mm

Compressive Strength of Stone masonry, fm = 2.50 MPa

Yielding strength of wire mesh, fy = 414 MPa

Diameter of mesh wire = 3 mm

Area of single wire =7.06 mm2

Steel area per meter width = 5 x 7.06 = 35.30 mm2

Depth of Whitney stress block, a= (As x fy)/(0.85 fm b) = 6.88 mm

Nominal Moment Capacity, Mn=As x fy (d-a/2) = 5.798 x106 N-mm/1000 mm

= 5798 kN-mm/m

Out of Plane Bending Moment Peak Demand from Numerical Model for RSA:

Table 6: Peak demand on out-of-plane bending walls, obtained from RSA

M22 Demand on stone masonry wall			M11 Demand on stone masonry wall		
Between support and sill	**Between sill and lintel**	**Between lintel and eave**	**Between support and sill**	**Between sill and lintel**	**Between lintel and eave**
(kN-mm/m)	**(kN-mm/m)**	**(kN-mm/m)**	**(kN-mm/m)**	**(kN-mm/m)**	**(kN-mm/m)**
15868	16.3	11260	8.93	5794	4.76

The out of plane bending demand at all locations is less than the capacity of wall. However, it is exceeded by about 20% between lintel and eave level. Based on the calculations and considering size of the available stones, the wire of the containment mesh spacing was proposed at 200mm spacing both horizontal and vertical. Containment mesh on both surfaces of the walls were tied together by cross ties passing through the walls. The vertical wires pass under the base and wrap around the wall.

3.3.2 Type Design 2

3.3.2.1 Gabion Bands

The idea of using galvanized welded wire mesh bands is similar to using RC or wooden seismic bands; as included in the guidelines proposed by the International Association of Earthquake Engineering (IAEE, 2013), which is also adopted by the Nepali Standards NBC203 (1998) and Indian Standards IS:4326 (1993). The typical gabion band comprised of a geogrid mesh/galvanized welded wire mesh that basket courses of stone masonry, wrapped around and tied through binding wires, see Figure 14. In the current case galvanized iron welded mesh has been used for bands. Gabion bands were modeled using frame elements, all gabion bands were assumed to be moment free and assigned with moment releases at their ends.

The numerical model was analyzed and the member tension and shear forces and bending moment were obtained, and the maxima were identified for band. The forces obtained were retrieved and processed to compute the tensile, shear and bending stresses in each member, which are compared with the permissible limits. The following provide details of the calculated forces for the gabion bands.

Figure 14: Newly proposed Gabion/Geogrid band for stone masonry

Design Calculation *for Gabion Bands*

Effective depth of band, d = 400 mm

Width of band, b = 200 mm

Compressive strength of stone masonry, fm = 2.50 MPa

Yielding strength of wire mesh, fy = 248 MPa

Diameter of mesh wire = 3 mm

Area of single wire =7.06 mm2

Steel area = 5 x 7.06 = 35.30 mm2

Depth of Whitney stress block, a= (As x fy)/ (0.85 fm b) = 28.60 mm

Nominal Moment Capacity, Mn = As x fy (d-a/2) = 3.376 x106 N-mm = 3376 kN-mm

Peak Demand on Gabion Bands from Response Spectrum Analysis:

Table 7: Peak demand on gabion bands at each level, obtained from RSA

Sill Band		Lintel Band		Eave Band	
Moment	**Shear**	**Moment**	**Shear**	**Moment**	**Shear**
(kN-mm)	**(kN)**	**(kN-mm)**	**(kN)**	**(kN-mm)**	**(kN)**
732	0.65	2289	9.7	1690	2.17

3.3.2.2 Containment Wires

The design and verification of wire containment mesh included the design of vertical and horizontal steel wires and specification of wires' spacing for application. The demand on wall was computed, as out of plane bending at multiple levels of wall, both vertical and horizontal, through response spectrum analysis of masonry building. The vertical and horizontal bending capacity of wall is calculated using the simple reinforced concrete section analogy that considers wire with tension capacity and stones to provide compression.

Out of Plane Bending Moment Capacity of Wall

Effective depth, d = 400 mm

Width of Wall, b = 1000 mm

Compressive Strength of Stone masonry, fm = 2.50 MPa

Yielding strength of wire mesh, fy = 276 MPa

Diameter of mesh wire = 3 mm

Area of single wire =7.06 mm2

Steel area per meter = 5 x 7.06 = 35.30 mm2

Depth of Whitney stress block, a= (As x fy)/(0.85 fm b) = 4.6 mm

Nominal Moment Capacity, Mn=As x fy (d-a/2) = 3.871 x106 N-mm/1000 mm

= 3871 kN-mm/m

Out of Plane Bending Moment Peak Demand from Numerical Model for RSA

Table 8: Peak demand on out-of-plane bending walls, obtained from RSA

M22 Demand on stone masonry wall			**M11 Demand on stone masonry wall**		
Between support and sill	**Between sill and lintel**	**Between lintel and eave**	**Between support and sill**	**Between sill and lintel**	**Between lintel and eave**
(kN-mm/m)	**(kN-mm/m)**	**(kN-mm/m)**	**(kN-mm/m)**	**(kN-mm/m)**	**(kN-mm/m)**
969	2638	1574	1171	3197	7310

The out of plane bending demand at all locations is less than the capacity of wall. However, it is exceeded by about 20% between lintel and eave level. Based on the calculations and considering size of the available stones, the wire of the containment mesh spacing was proposed at 200mm spacing both horizontal and vertical. Containment mesh on both surfaces of the walls tied together by cross ties passing through the walls. The vertical wires pass under the base and wrap around the wall.

3.3.3 Type Design 3

3.3.3.1 RC Bands

Design Calculation for Seismic Analysis Bands

Effective depth of band, d = (380-30) = 350 mm

Width of band, b = 75 mm

Compressive Strength of Concrete, fc’ = 10 MPa (1.5 ksi)*

Yielding strength of steel bar, fy = 500 MPa

Diameter of bar = 12 mm

Area of single bar =113 mm2

Steel area = 1 x 113 = 113 mm2

Depth of Whitney stress block, a= (As x fy)/(0.85 fc' b) = 85.9 mm

Nominal Moment Capacity, Mn=As x fy (d-a/2) = 17.39 x106 N-mm = 17390 kN-mm

Peak Demand on RCC Bands from Response Spectrum Analysis

Table 9: Peak demand on seismic bands at each level, obtained from RSA

Eave Band		Lintel Band		Sill Band	
Moment	**Shear**	**Moment**	**Shear**	**Moment**	**Shear**
(kN-mm)	**(kN)**	**(kN-mm)**	**(kN)**	**(kN-mm)**	**(kN)**
15,743	11.28	12,368	9.9	6,674	4.7

Gravity Analysis for the Lintel Band Above the Openings

Flexure Design of RC band

Load from roof = .135 kN/m

Load of earth brick Wall on Lintel band above openings = 4.30 kN/m

Self-weight of Lintel Band above openings = 1.11 kN/m

Factored Load = 1.2*(0.135+4.3+1.11) = 6.65 kN/m

Bending moment = 6.65*1.2^2/9 = 1.06kNm

Depth of RC band = 125 mm

Effective depth of RC band, d = (125-30) = 95 mm

Width of band, b = 380 mm

Compressive Strength of concrete, fc' = 10 MPa (1.5 ksi)

Yielding strength of steel bar, fy = 500 MPa

Diameter of bar = 12 mm

Area of single bar =113 mm2

Steel area = 1 x 113 = 113 mm2

Depth of Whitney stress block, a= $\frac{As*fy}{0.85*fc'*b}\frac{Ø*2*\sqrt{fc\prime}*b*d}{1000}$ = 18 mm

Nominal Moment Capacity, Mn=As x fy (d-a/2) = 6.65 kN-m

Capacity to Demand ratio = 6.65/1.06 = 6.27

Shear Design of RC band

Shear demand = 4.58 kN

Shear capacity = ØVc =$\frac{Ø*2*\sqrt{fc\prime}*b*d}{1000}$ = 15.4 kN

ØVc/2 = 15.4/2 = 7.7 theoretically no need of web Reinforcement.

3.3.3.2 Vertical Re-bars

The design of vertical re-bars included the assessment of vertical bar carrying tension loads. The vertical re-bar was modeled as an RC frame element, RC section was defined in section designer and provided with single steel bar in center, with appropriate dimensions equal to the pocket size (half-brick square). The model was analyzed through response spectrum analysis. The vertical tension capacity of vertical re-bar was calculated as the tension capacity of single steel bar.

Out of Plane Bending Moment Capacity of Wall

Bar diameter = 8 mm

Bar area = 50.24 mm2

Yielding strength of bar = 500 MPa

Nominal tension capacity = yielding strength * bar area = 500*50.24

Nominal tension capacity = 25120 N

Nominal tension capacity = 25.12 kN

Out of Plane Bending Moment Peak Demand from Numerical Model for RSA

Maximum demand on the tension members is 15.70 kN, which is less than the tension capacity of vertical members.

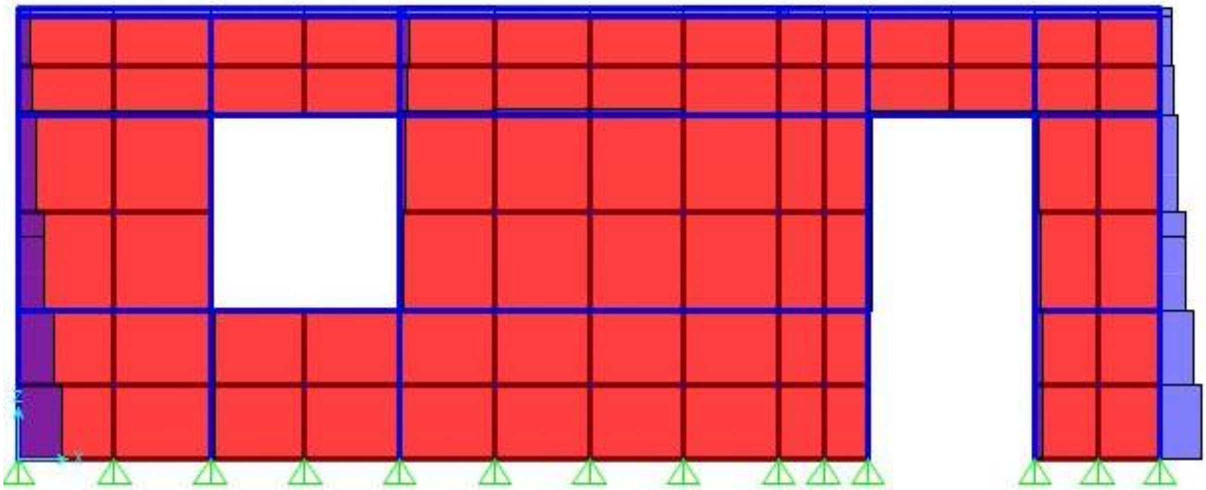


Figure 15: Tension forces in vertical members from RSA.

3.3.4 Type Design 4

3.3.4.1 Timber Bands

Wooden seismic bands as included in the guidelines proposed by the International Association of Earthquake Engineering (IAEE, 1986) and also adopted by the Indian Standards IS:13828 (1993) provide sizes and details for the wooden seismic bands. The typical band comprised of a wooden ladder type reinforcement that composed of two main members 75mm x 38mm (Runners) connected through cross members 50mm x 30mm (Spacers), see Fig. 16.

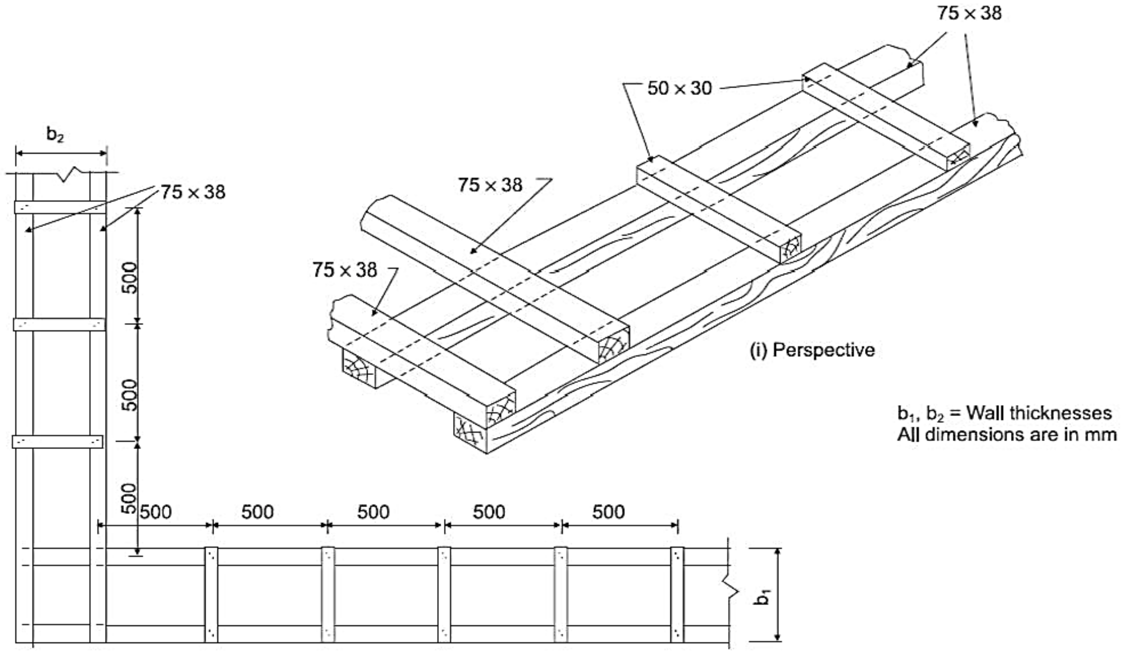


Figure 16: Wooden seismic band, IAEE (2004, 1986)

The model was analyzed and the member tension and shear forces and bending moment were obtained. The maxima were identified for each runners and spacers. The forces obtained are retrieved and processed to compute the tensile, shear and bending stresses in each member, which are compared with the permissible limits. Since, the timber bands runners and spacers were subjected to stresses more than the allowable limit, the timber band scheme (layout) was modified (see Figure 17) from the originally proposed by IAEE 2013. The modified timber band also included diagonal members, included with the intention to increase band stiffness and minimize the lateral deflection of bands. The following provide details of the calculated forces for the modified timber bands, which show reasonable performance of the timber band.

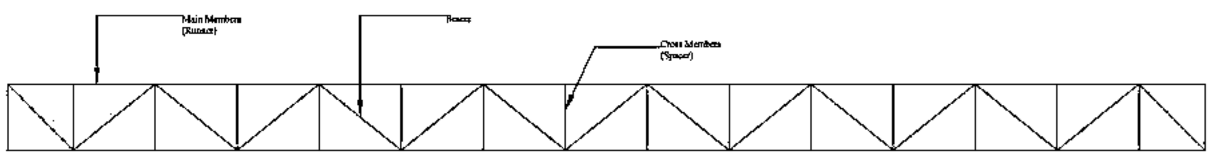


Figure 17: Details of modified timber bands in CSI SAP2000

Design calculation for timber bands

Out-of-plane moment demand on timber bands of prototype building taken from numerical model is shown in Table 10. Out-of-plane axial and shear capacity of the timber band is calculated using reinforced concrete analogy as given below

Cross sectional area of Runners = (75x38) =2850 mm2

Cross sectional area of Spacers and Diagonal = (50x30) =1500 mm2

Tensile strength of timber = 5.8 MPa

Shear Strength of timber = 0.57 MPa

Tension capacity = tensile strength * cross-sectional area

Tension capacity of runners = 5.8*2850/1000 = 16.53 kN

Tension capacity of spacers = 5.8*1500/1000 = 8.7 kN

Shear capacity = shear strength * cross sectional area

Shear capacity of runners = 0.57*2850/1000 = 1.62 kN

Shear capacity of spacers = 0.57*1500/1000 = 0.855 kN

Table 10: Peak demand on timber bands at each level, obtained from RSA

Sill Band				Lintel band				Eave band			
Runner		Spacers		Runner		Spacers		Runner		Spacers	
Tension	Shear (V_3)	Tension	Shear (V_3)	Tension	Shear (V_3)	Tension	Shear (V_3)	Tension	Shear (V_3)	Tension	Shear (V_3)
(kN)	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)
6.04	0.367	0.967	0.609	13.57	0.778	6.3	0.644	17.8	0.789	7.17	0.78

Thus, the nominal moment capacity is greater than the demand on timber band.

3.3.4.2 Containment Wires

Out-of-plane moment demand on stone masonry wall of prototype building taken from the numerical model shown in Table 11.

Table 11: Demands on walls

M_{22} Demand on stone masonry wall			M_{11} Demand on stone masonry wall		
Between support and sill	**Between sill and lintel**	**Between lintel and eave**	**Between support and sill**	**Between sill and lintel**	**Between lintel and eave**
(kN-mm/m)	**(kN-mm/m)**	**(kN-mm/m)**	**(kN-mm/m)**	**(kN-mm/m)**	**(kN-mm/m)**
1136	2094	1341	1402	3309	5107

Out-of-plane moment capacity of the wall is calculated using reinforced concrete analogy is given below:

Effective depth, d = 400 mm

Width of Wall, b = 1000 mm

Compressive Strength of Stone masonry, fm = 2.5 MPa

Yielding strength of wire mesh, fy = 414 MPa

Diameter of mesh wire = 3mm

Area of single wire =7.06 mm2

Steel area per meter = 5 x 7.06 = 35.30 mm2

Depth of Whitney stress block, a= (As x fy)/(0.85 fm b) = 6.88 mm

Nominal Moment Capacity, Mn=As x fy (d-a/2) = 5.798 x106 N-mm/1000 mm

= 5798 kN-mm/m

The demand on wall is less than the capacity of stone masonry wall.

3.4. Design Details of Test Models

The design of structural components performed on the basis of numerical modelling and analysis of prototype of all Type Designs were transformed to test models as per the applicable similitude requirements for simple model idealization of both 2/3rd and 1/3rd scale. This involved linear scaling of all dimensions of walls, bands and reinforcement, etc. In case of unavailability of exact required sizes of rebars, the necessary conservative approximations were made. Geometric and reinforcement details of test models for Type Design 1, 2, 3, and 4 are shown in Appendix C1 to C4 for 2/3rd and D1 to D4 for 1/3rd scaled models, respectively.

CHAPTER 4: EXPERIMENTAL PROGRAM – CONSTITUENT MATERIALS

4.1 Basic Tests on Materials and Sub-Assemblages

This section includes description of tests carried out for the estimation of mechanical properties of the constituents of masonry such as units (stone/brick), cement stabilized and unstabilized mud-mortar as well as the properties of masonry assemblages i.e. masonry prisms, wallettes and piers (walls). Mechanical properties such as compressive strength, shear and diagonal tensile strength, compression and shear moduli were determined. The tests were performed using the following standard testing procedures:

- ASTM E-519-02c for wallettes tests,
- ASTM C-67-06 for masonry unit tests,
- ASTM C109/C109M-08 for mortar compression tests,
- ASTM C-1314-07 for masonry compression tests,
- E-519-02 and RILUM LUM B6 for shear and diagonal tension tests on masonry wallettes.

Table 12 shows details of specimens' tests relevant to stone masonry construction of models of all Type Designs (Type 1, Type 2 and Type 4) while Table 13 shows details of specimens' tests relevant to CSEB model (Type 3).

While constructing test specimens, attempts were made to simulate the field conditions of the earthquake-affected areas of Nepal. To simulate the field conditions, quality control of the construction materials and skills was kept to a minimum. This resulted in large variation in test results.

Table 12: Tests on constituent materials and sub-assemblages (Type 1, 2 and 4)

S. No.	Test Type	Samples						
		Cement stabilized mud mortar	**Cement stabilized mud mortar with wall surface containment**	**Unstabilized mud mortar without containment**	**Dry Masonry**	**Unstabilized mud mortar with wall surface containment**	**Wires**	**Total********
1	Compressive Strength Tests of Stone cores	-	-	-	4	-	-	4
2	Compressive Strength Tests of Mortar cubes	33	-	69	-	-	-	102
3	Galvanized wire-tension test		-		-	-	(3+3) containment+(3+3) stitch+(3+3) cross ties + (3+3) Gabion	24
4	Stone masonry compression prisms	3	-	3	3	1	-	10
5	Direct in-plane shear and diagonal tension test	-	1	1	-	4	-	6
6	In-plane quasi static shear tests on stone masonry walls	-	-	1	-	3	-	4

Table 13: Tests on constituent materials and sub-assemblies (Type 3)

S. No.	Test Type	Samples
		In cement stabilized mud mortar only
1	Brick Units	$6 = 3^{*} + 3^{**}$
2	Mortar cubes	$15 = 6^{*} + 9^{**}$
3	Re-Bar Test	3
4	Compression Prism Tests	3
5	Concrete Cylinder Tests	$17 = 9^{*} + 8^{**}$
6	Direct in-plane shear and diagonal tension test	3
7	In-plane quasi static shear tests on CSEB masonry walls	2

*: Cubes obtained during construction of $2/3^{rd}$ scale model for each Type Design
**: Cubes obtained during construction of $1/3^{rd}$ scale model for each Type Design
***: The numbers are cumulative

4.2 Units Tests

Stone Cores: The ASTM proposes C170-06 for compressive strength evaluation of stone units. Core cutter was used to extract cores from the procured stones; core having diameter 1.75 inch (44.50 mm) and length 3.63 inch (92 mm), with a height to diameter ratio of about 2.0. Four samples were tested in compression in UTM giving compressive strength of 13,338 psi, 7,860 psi, 10,370 psi and 10,699 psi respectively, with an average compressive strength of 10, 566 psi (72.87 MPa) with a coefficient of variation of 21.20%.

Figure 18: Extracted stone cores for compression tests

CSEB Units: Compression tests were performed on CSEB unit in accordance to section 6 of ASTM C-67. The test specimens were tested flat wise (that is the load was applied in the direction of depth of brick) in accordance with section 6.3.1 of the ASTM standard. The average compressive strength was found to be 714.45 psi (4.92 MPa) with a coefficient of variation of 5.21%.

Figure 19: Brick Unit compression tests

4.3 Mortar Cubes

Mortar specimens were prepared during construction of both the 1/3rd and 2/3rd test models. Mortar cubes of size 2 inch x 2 inch x 2 inch (50.8 mm x 50.8 mm x 50.8 mm) were prepared as per the design specifications. Compressive strength tests of mortar cubes were conducted in accordance with ASTM C-109. The specimens were tested after 28 days. The average compressive strength of cement stabilized mud mortar cubes was 118 psi (0.814 MPa) with a coefficient of variation of 53.43%, while the compressive strength of unstabilized mud mortar cubes was 251.22 psi (1.73 MPa) with a coefficient of variation of 29.17%. Appendix B1 (Type 1), Appendix B2 (Type 2), Appendix B3 (Type 3), Appendix B4 (Type 4) reports the model specific mortar tests.

Figure 20: Mortar cube compression tests

4.4 Galvanized Wire Tests

Wires used in containment, stitches, crossties and gabion mesh of both 2/3rd and 1/3rd scale models were tested. Table 14 describes wires types while Table 15 and 16 reports properties of tested wires, for each 2/3rd and 1/3rd scale models, measured tension load carrying capacity and calculated yield (tension) strength.

Table 14: Description of galvanized wire types used in each 2/3rd and 1/3rd model

S. No.	Items	Full Scale Model	2/3rd Scale Model	1/3rd Scale Model
1	Containment Mesh	3 mm (11-G) @ 200*200	2 mm (14-G) @ 133*133	1 mm (19-G) @ 67*67
	Acquired from Market		2 mm (14-G) @ 133*133	1 mm (19-G) @ 67*67

2	WWM for Stitches	4 mm (8-G) @ 100*100	2.66 mm (12-G) @ 67*67	1.33 mm (17-G) @ 34*34
	Acquired from Market		2 mm (14-G) @ 50*50	1.33 mm (17-G) @ 25*25
3	Wire for Cross ties	2 mm (14-G) @ 200*200	1.33 mm (17-G) *2 @ 133*133	.67mm (23-G) *2 @ 67*67
	Acquired from Market		1.33 mm (17-G) *2 @ 133*133	1 mm (19-G) *2 @ 67*67
4	Gabion Mesh	3 mm (11-G) @ 50*50	2 mm (14-G) @ 33*33	1 mm (19-G) @ 17*17
	Acquired from Market		1.33 mm (17-G) @ 25*25	1 mm (19-G) @ 18*18

Table 15: Tests on galvanized wires used in 2/3rd model

S. No	Description	Diameter, in (mm)	Area, sq-in (mm^2)	Force (tons)	Yield Stress, ksi (MPa)	CoV* (%)
1	Containment Mesh	0.079 (2.00)	0.005 (3.226)	0.140	63.30 (436.44)	1.45
		0.079 (2.00)	0.005 (3.226)	0.138	62.39 (430.16)	
		0.079 (2.00)	0.005 (3.226)	0.136	61.50 (424.07)	
2	WWM for Stitches	0.079 (2.00)	0.005 (3.226)	0.102	46.12 (317.99)	3.90
		0.079 (2.00)	0.005 (3.226)	0.110	49.73 (342.88)	
		0.079 (2.00)	0.005 (3.226)	0.108	48.83 (336.67)	
3	Wire for Cross ties	0.052 (1.32)	0.002 (1.290)	0.062	63.40 (437.13)	0
		0.052 (1.32)	0.002 (1.290)	0.062	63.40 (437.13)	
		0.052 (1.32)	0.002 (1.290)	0.062	63.40 (437.13)	

*: Coefficient of variation

Table 16: Tests on galvanized wires used in 1/3rd model

S. No	Description	Diameter, in (mm)	Area, sq-in (mm^2)	Force (tons)	Yield Stress, ksi (MPa)	CoV (%)
1	Containment Mesh	0.039 (1.00)	0.001 (0.645)	0.052	94.04 (648.38)	0
		0.039 (1.00)	0.001 (0.645)	0.052	94.04 (648.38)	
		0.039 (1.00)	0.001 (0.645)	0.052	94.04 (648.38)	
2	WWM for Stitches	0.052 (1.321)	0.002 (1.290)	0.052	53.16 (366.53)	0
		0.052 (1.321)	0.002 (1.290)	0.052	53.16 (366.53)	
		0.052 (1.321)	0.002 (1.290)	0.052	53.16 (366.53)	
3	Wire for Cross ties	0.039 (1.00)	0.001 (0.645)	0.052	94.04 (648.38)	0
		0.039 (1.00)	0.001 (0.645)	0.052	94.04 (648.38)	
		0.039 (1.00)	0.001 (0.645)	0.052	94.04 (648.38)	
4	Gabion Mesh	0.039 (1.00)	0.001 (0.645)	0.048	86.81 (598.53)	2.37
		0.039 (1.00)	0.001 (0.645)	0.048	86.81 (598.53)	
		0.039 (1.00)	0.001 (0.645)	0.050	90.42 (623.42)	

(Note: Numbers in parenthesis are in SI units)

4.5 Masonry Assemblage Compression Tests

Masonry prisms tests were conducted in accordance with ASTM C-1314. The specimens were prepared in accordance with the model's design specifications. Average size of each specimen was approximately 296 mm x 285 mm x 165 mm, to simulate the test specimens of 2/3rd scale model, (Figure 21). After a curing period of about 7 days these specimens were tested. Concrete pads were placed on the top and bottom of prisms to apply the vertical load uniformly using a load cell. Load was applied incrementally using 200-ton UTM machine till the masonry unit's splitting/crushing was observed.

Figure 21:Compression tests on masonry prisms, Stone (left) CSEB (right)

Each dimension of length, width and thickness was measured at four points on the sample and an average value was considered. The compressive strength was calculated as follows:

$$\text{Compressive Strength of Prism} = \frac{Load\ at\ Failure}{Length\ x\ Width}$$

Modulus of Elasticity: Modulus of elasticity of masonry was determined based on the data acquired from masonry compression tests. Deformation gauges were mounted on samples to determine axial deformations (compression). Since, concrete pads were used at the top and bottom of the test specimens, corrections were applied to the acquired stress-strain relationships. Figure 22 shows averaged combined plot.

Procedure for the determination of the Modulus of Elasticity "E" of the masonry prism as given by ASTM standard is as follow:

$$E = \Delta\ \text{Stress}/\ \Delta\ \text{Strain}$$

where

Δ Stress = (Stress corresponding to 1/3 of the compressive strength) - (Stress corresponding to 1/20 of the compressive strength)

Δ Strain = Difference of the strain at corresponding values of stress.

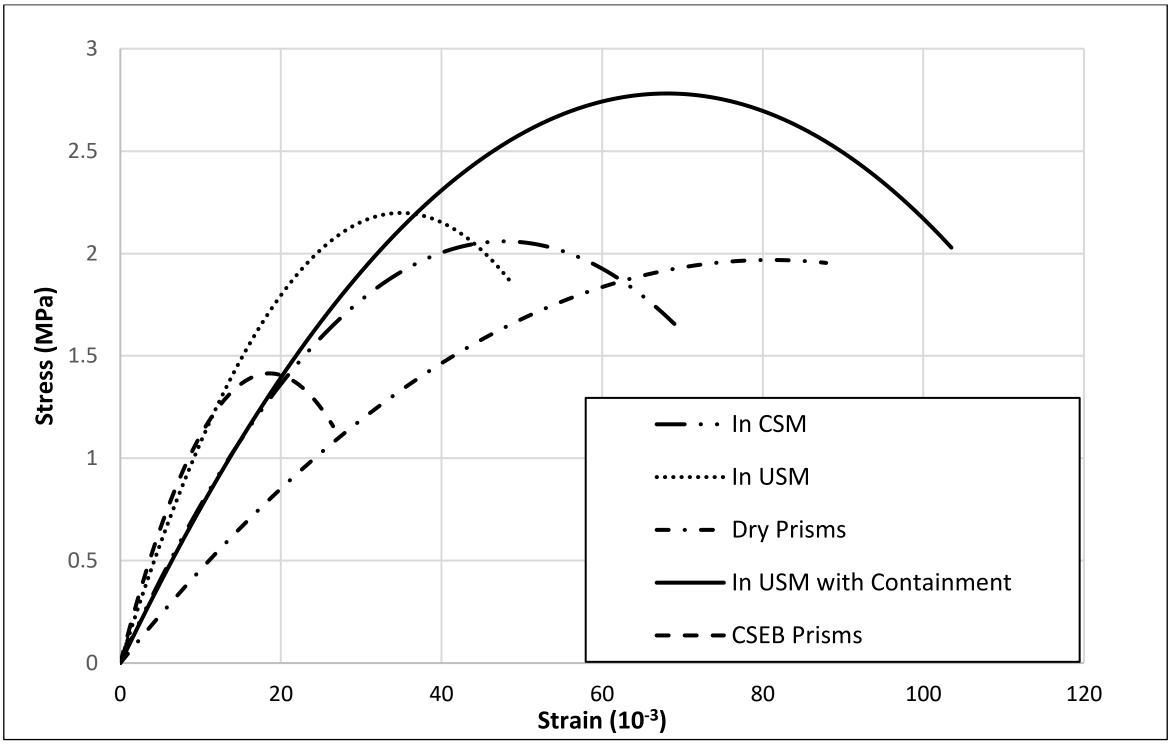


Figure 22: Combined plot of all samples

(CSM: Stone Masonry in Cement Stabilized Mud Mortar, USM: Stone Masonry in Mud Mortar)

Table 17: Basic mechanical properties of stone and CSEB masonry

S. No.	Description	Compressive Strength, fc' (MPa)			Modulus of Elasticity, E (MPa)			Avg. fc' (MPa)	CoV (%)	Avg. E (MPa)	CoV (%)
		Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3				
1	Stone Prisms in Cement Stabilized Mud Mortar	2.09	2.49	2.32	90.63	66.67	86.20	2.30	8.72	81.17	15.70
2	Stone Prisms in Unstabilized Mud Mortar	2.80	3.04	1.95	300.00	107.14	46.15	2.59	22	151.09	87.7
3	Dry Stone Prisms	1.79	2.08	-	45.45	33.33	-	1.93	10.62	39.39	21.75
4	Stone Prisms in Mud Mortar with wire containment	2.62	-	-	75.00	-	-	2.62	-	75.00	-
5	**CSEB** in cement stabilized mud mortar	1.39	1.36	1.45	133.30	105.26	222.22	1.40	3.27	153.59	39.75

4.6 Direct In-Plane Shear and Diagonal Tension Test

The test for the computation of shear strength properties was carried out in accordance with ASTM E-519 and RILEM LUM B6. Representative of size 4' x 4', scaled close to 2/3rd, were prepared as per the design specification, and tested in the loading frame in the diagonal direction. Due to the low strength nature of stone and CSEB masonry, the specimens were not possible to be tested diagonally using the classical vertical load arrangement for diagonal loading. Instead a special arrangement was designed to apply the load diagonally to the vertically standing wall, imposing diagonal load/deformation in wallettes (Figure 23).

Diagonal tension strength is calculated directly; dividing the failure load over the area (average sides' length x wall thickness). This loading setup provides information on the diagonal applied load and induced deformations (i.e. diagonal shortening and elongation), the basic mechanics formulae was used to transform diagonal force-deformation to lateral force-deformation in order to obtain the in-plane shear strength (τ_0), diagonal tension strength (f_{tu}) and shear deformability (θ) of wallettes.

Figure 24 shows the damage pattern of the wallette at the ultimate state. Figure 25 to 28 shows the shear stress versus shear strain behavior of tested wallettes, while Figure 29 shows combined plot of all specimens. Figure 30 to 32 shows the damage evolution of tests wallettes under diagonal compression loading.

Shear stress-strain relationship and diagonal tension strength were calculated as follows:

$$t_0 = \frac{0.707P}{A_n}; A_n = W \, x \, t$$

$$q = \frac{(D_{d1} + D_{d2})}{L_g}$$

$$f_{tu} = \frac{0.5P}{A_n}$$

where, W represents the wall width/length (average is taken) and t represents the wall thickness; Δd1 and Δd2 represents the recorded deformation in the horizontal and vertical diagonal respectively; Lg represents the gauge length (distance between the reference points considered along horizontal and vertical diagonals). Table 18 reports the mechanical properties of the masonry wallette; specifically shear strength, shear modulus, diagonal tension strength. All specimens exhibit very similar elastic stiffness and cracking shear, however, peak strength and ultimate strain were observed with larger uncertainties.

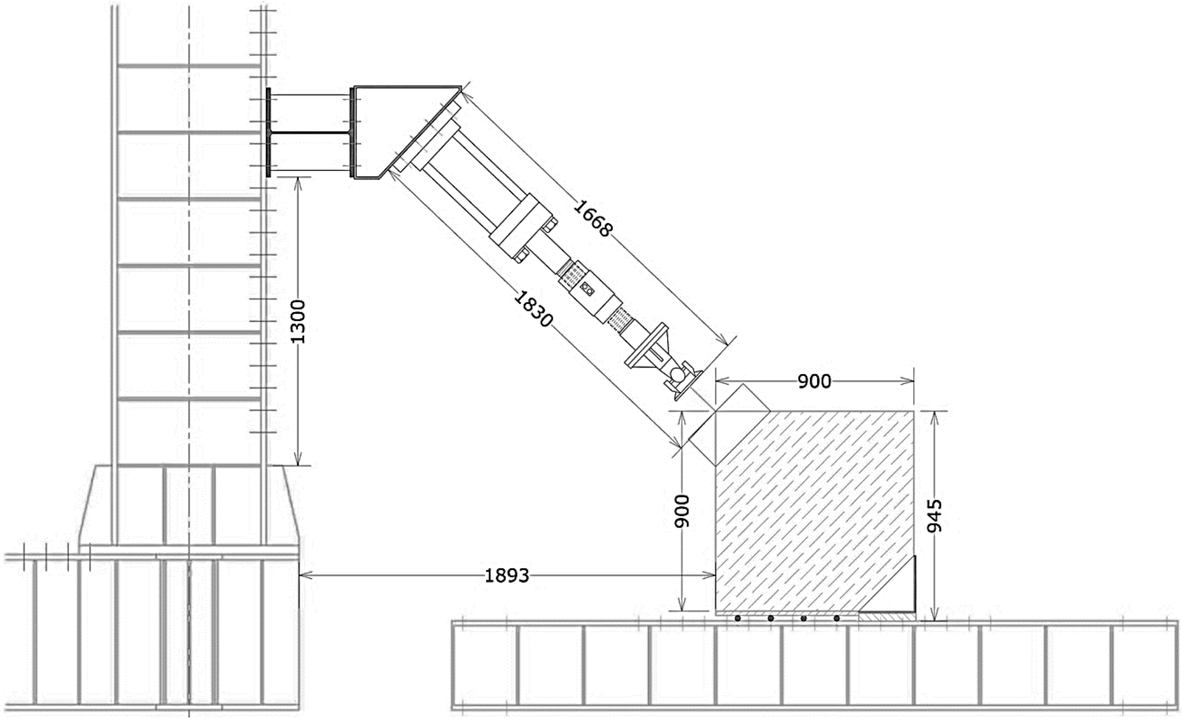


Figure 23: Diagonal Compression Test Setup

Figure 24: Ultimate damage state of Wallette under diagonal applied load, Stone with surface containment (left) CSEB (right)

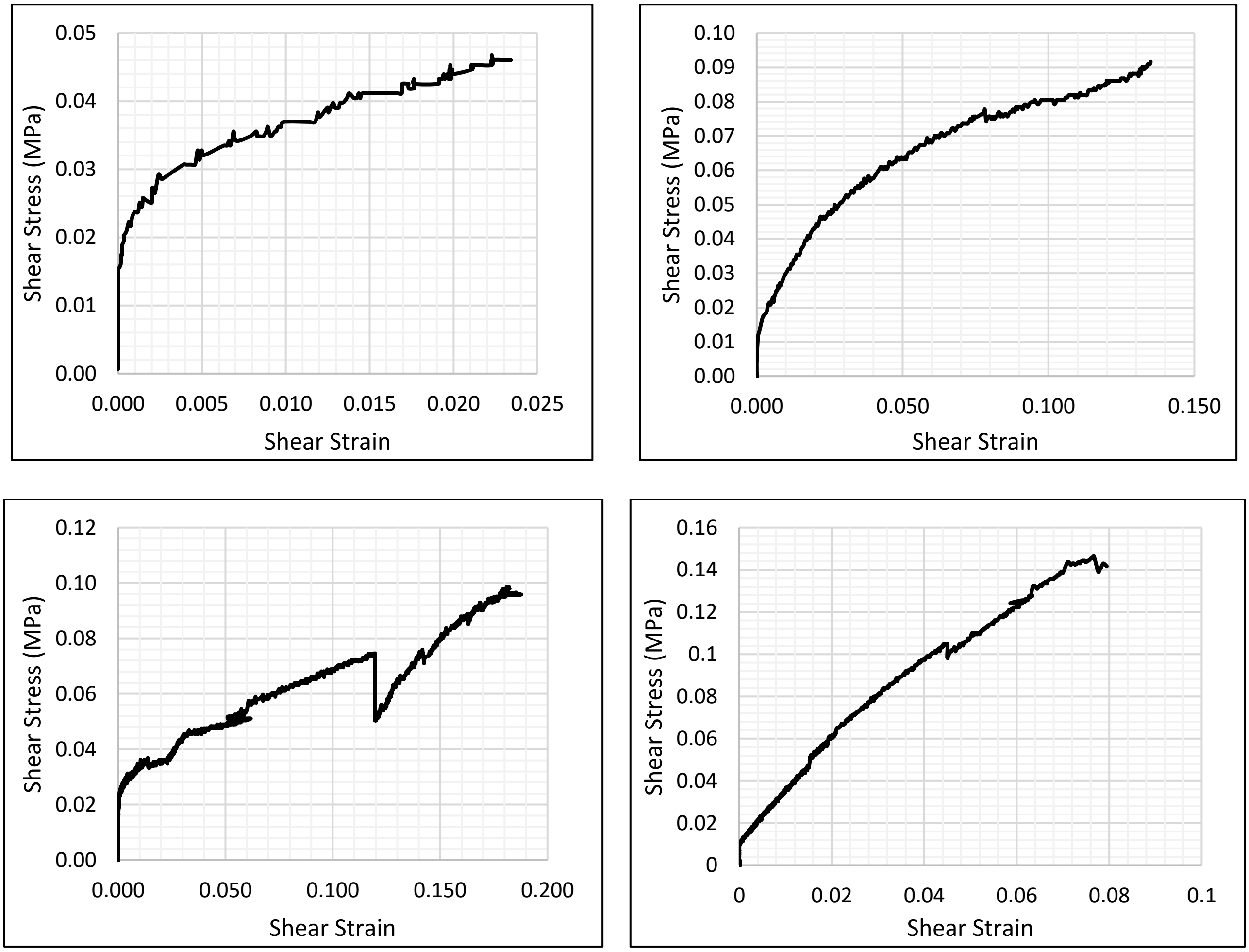


Figure 25: Stone Masonry Wallette in Unstabilized Mud Mortar with wire containment

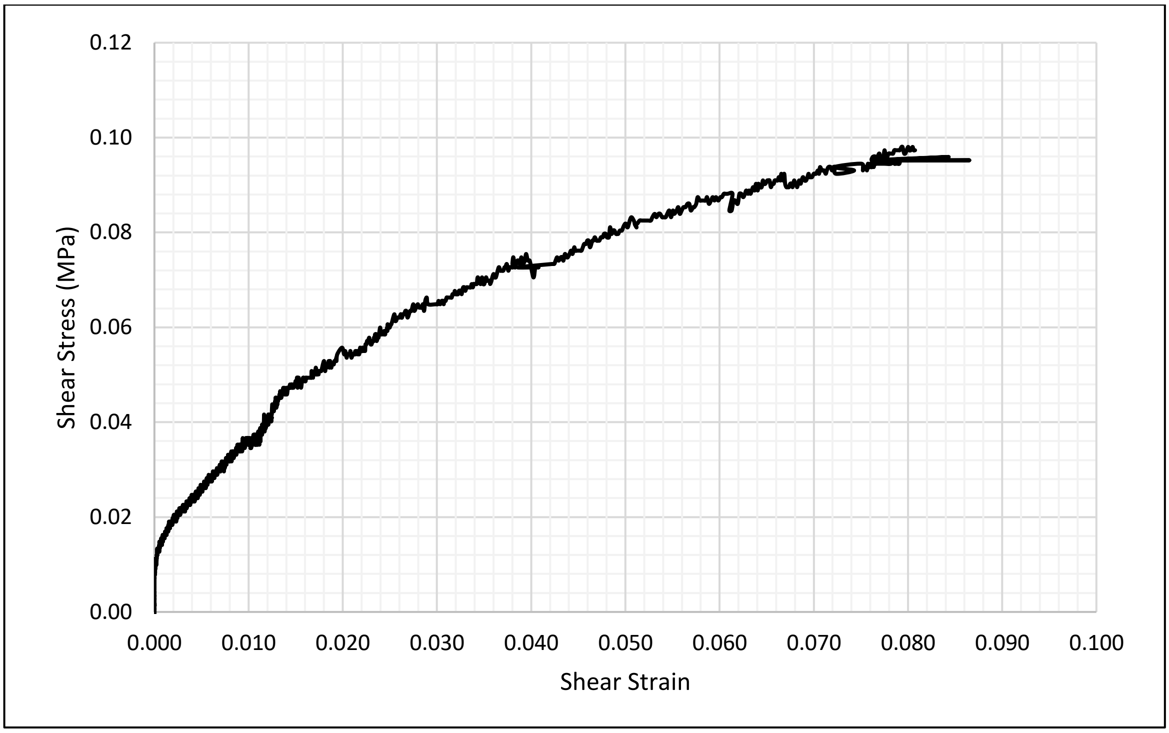


Figure 26: Stone Masonry Wallette in Unstabilized Mud Mortar without wire containment

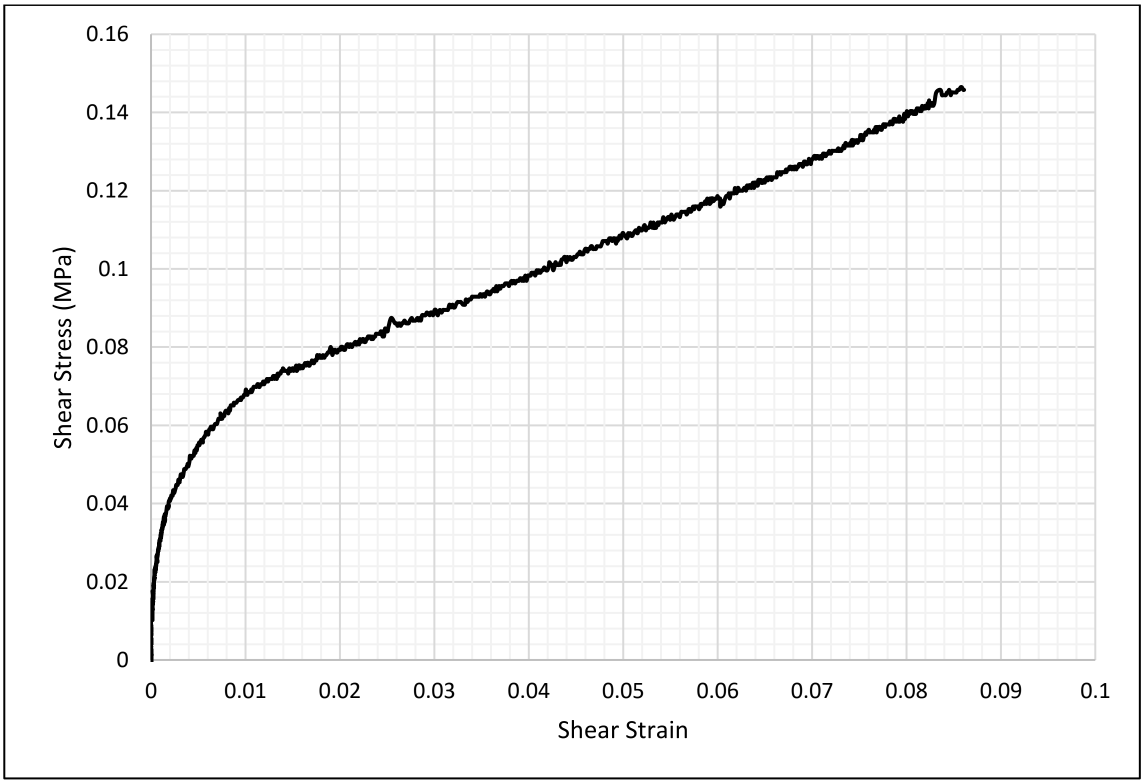


Figure 27: Stone Masonry Wallette in cement stabilized Mud Mortar with wire containment

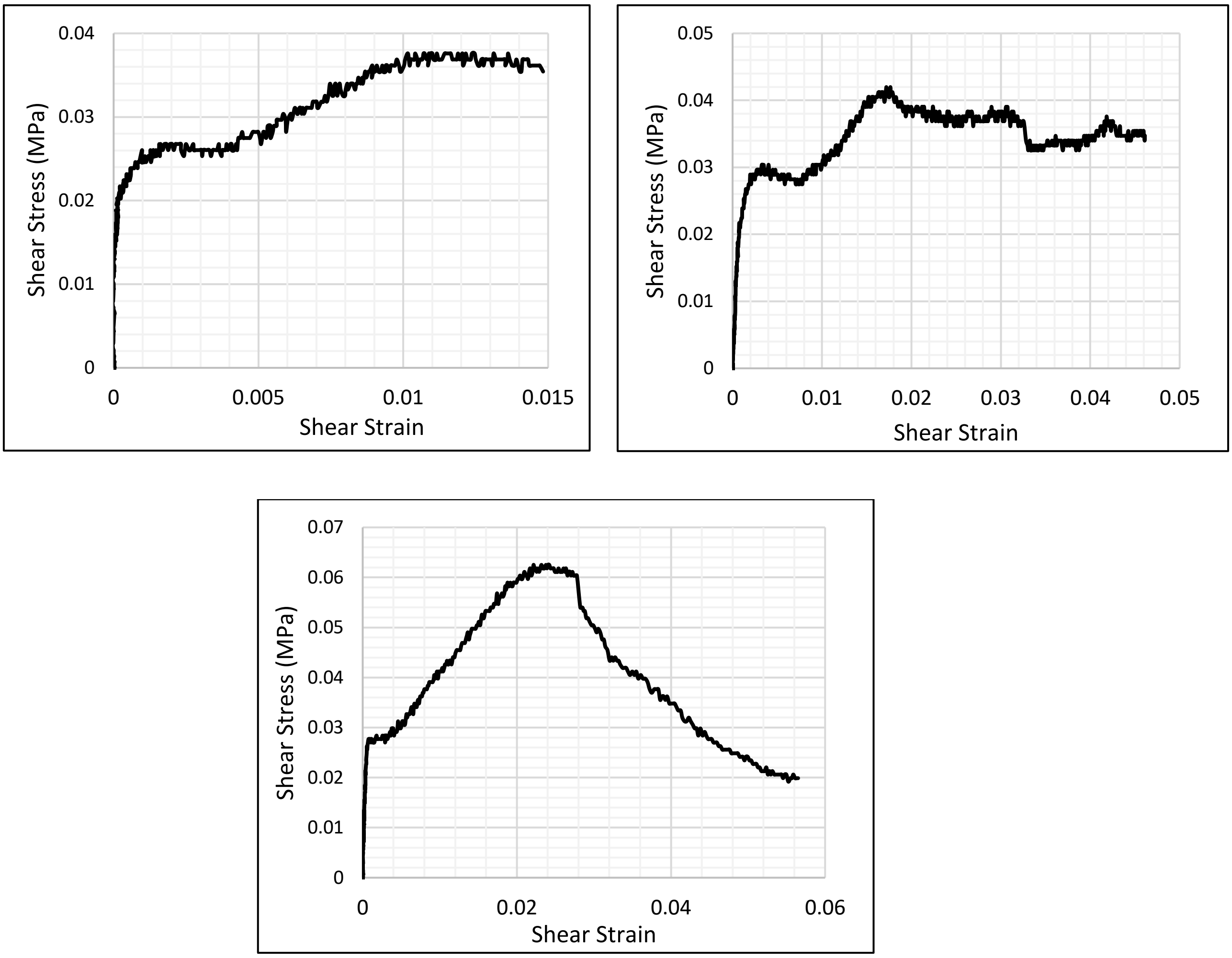


Figure 28: CSEB Masonry Wallette in cement stabilized Mud Mortar

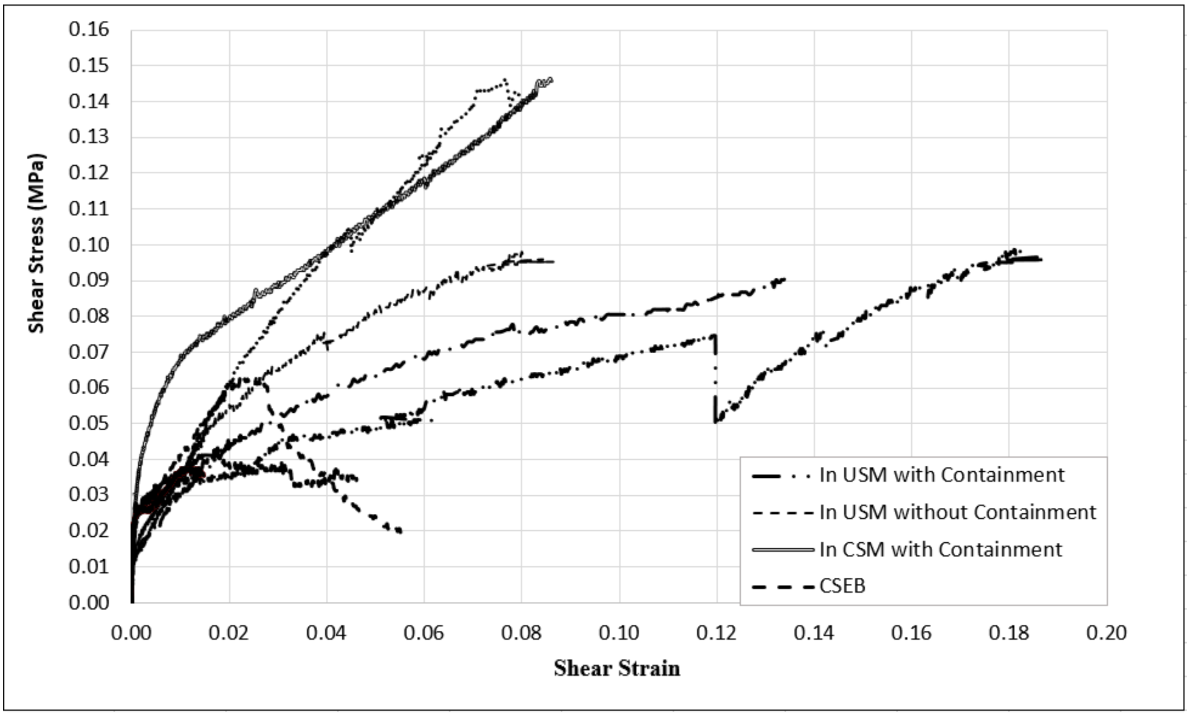


Figure 29: Combined plot of all samples

Note: Altogether they are 9 plots, however, some plots are hidden behind the other.

(CSM: Stone Masonry in Cement Stabilized Mud Mortar, USM: Stone Masonry in Mud Mortar)

Table 18: Mechanical properties obtained from diagonal compression test

S. No	Description	Stone wallettes in Cement stabilized mud mortar with wall surface containment	Stone wallettes in Unstabilized Mud Mortar with wall surface containment						Stone Wallettes in unstabilized Mud Mortar without wall surface containment	CSEB Wallettes in cement stabilized mud mortar				
	Samples	**S-1**	**S-1**	**S-2**	**S-3**	**S-4**	**Avg.**	**CoV (%)**	**S-1**	**S-1**	**S-2**	**S-3**	**Avg.**	**CoV (%)**
1	Diagonal Tensile Strength (MPa)	**0.104**	0.08	0.08	0.07	0.098	**0.082**	14.22	**0.07**	0.027	0.030	0.044	**0.034**	26.68
2	Shear Strength (MPa)	**0.146**	0.11	0.11	0.10	0.139	**0.115**	14.64	**0.10**	0.038	0.042	0.063	**0.047**	28.57
3	Modulus of Rigidity (MPa)	**12.204**	3.32	2.32	4.11	3.309	**3.26**	22.48	**4.08**	-	27.97	41.67	**34.82**	27.82

Figure 30: Damage evolution of the stone masonry wall in unstabilized mud mortar under diagonal tension test – without containment

Figure 31: Damage evolution of the stone masonry wall in unstabilized mud mortar under diagonal tension test – with containment

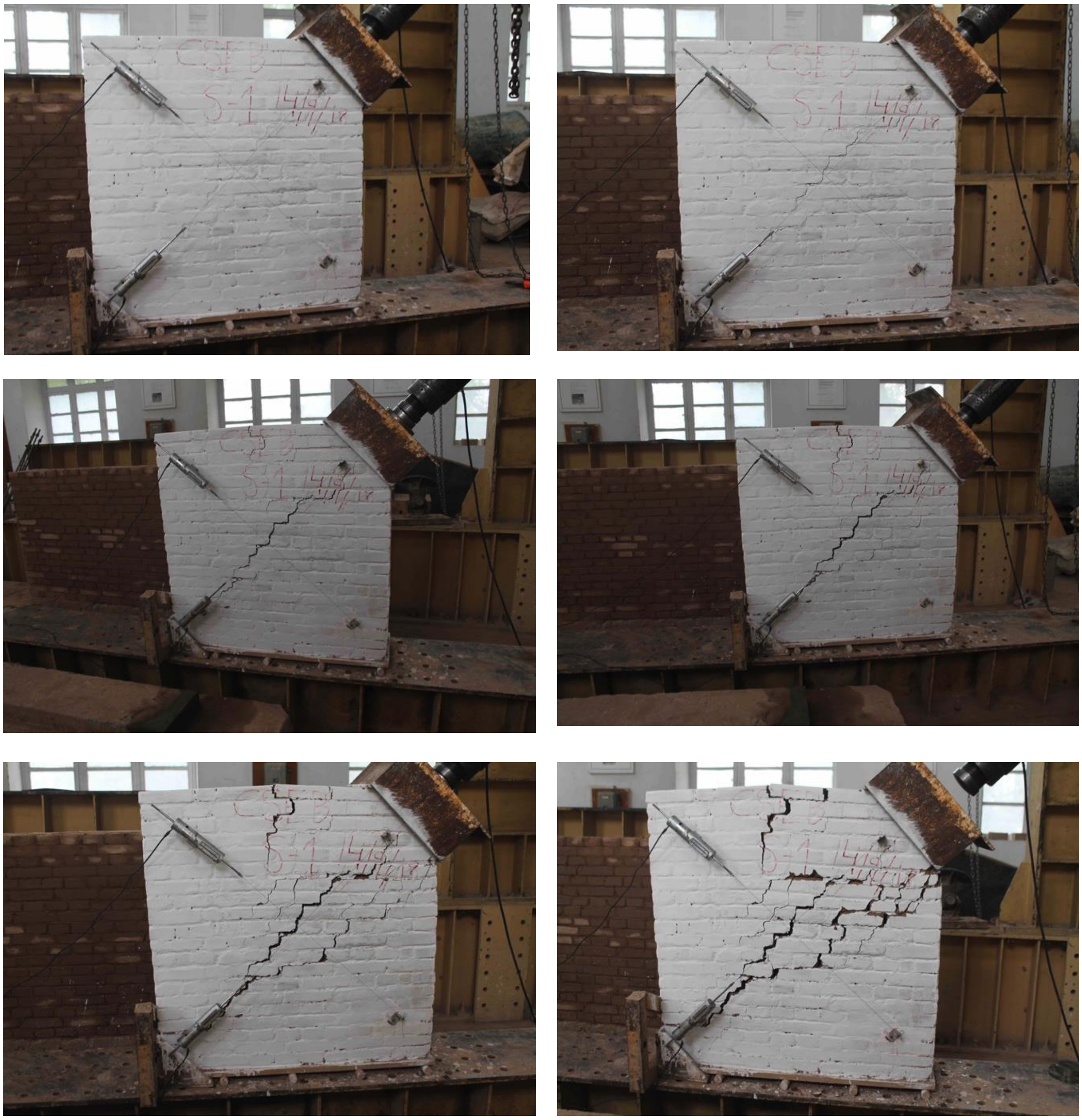


Figure 32: Damage evolution of the CSEB wall under diagonal tension test

4.7 In-Plane Quasi-static Cyclic Tests on Masonry Walls

For in-plane shear tests on masonry walls, a short pier was considered for quasi-static cyclic testing, specifically the pier between sill and lintel level. The pier was subjected to pre-compression; 975 kg and 758 kg in case of stone and CSEB masonry, respectively, and a lateral load through displacement-controlled horizontal actuator (50-ton capacity), as shown in Figure 33. The bottom concrete beam is fixed with test floor while the top end (also provided with RC beam) is allowed to freely rotate and translate. The load is measured with load cells. Displacement transducers are used to record the lateral displacements. The load cells and displacement transducers are attached to a data acquisition system. In-plane lateral displacements are measured through gauges 1 and 2 installed on front and back face of the specimen at the level of horizontal load.

Four displacement transducers were used to measure displacement at four different locations as shown in Figure 33. String pots 1 and 2 were used to measure horizontal displacements at the horizontal load level on both faces of the specimen while gauge 3 and 4 were used to record vertical rocking displacements at both ends of the specimen. All these load and displacement gauges were connected to the data acquisition system, UCAM-70.

The tests were performed in a displacement-controlled environment, using gauge 1 as the controlled displacement. Each displacement cycle was applied to a specified displacement level and repeated three times. The specified displacements were applied and increased incrementally or till the specimen was found in unstable condition. Each displacement cycle was completed in about 75 to 125 seconds at a variable displacement rate, low for small displacement cycle and high for large displacement cycle, test data recorded at a scanning speed of about 4 samples per second. The specimen was thoroughly examined and photographed for the cracks produced in it after each set of target displacement. The tests were halted when the specimen was found in the incipient collapse state.

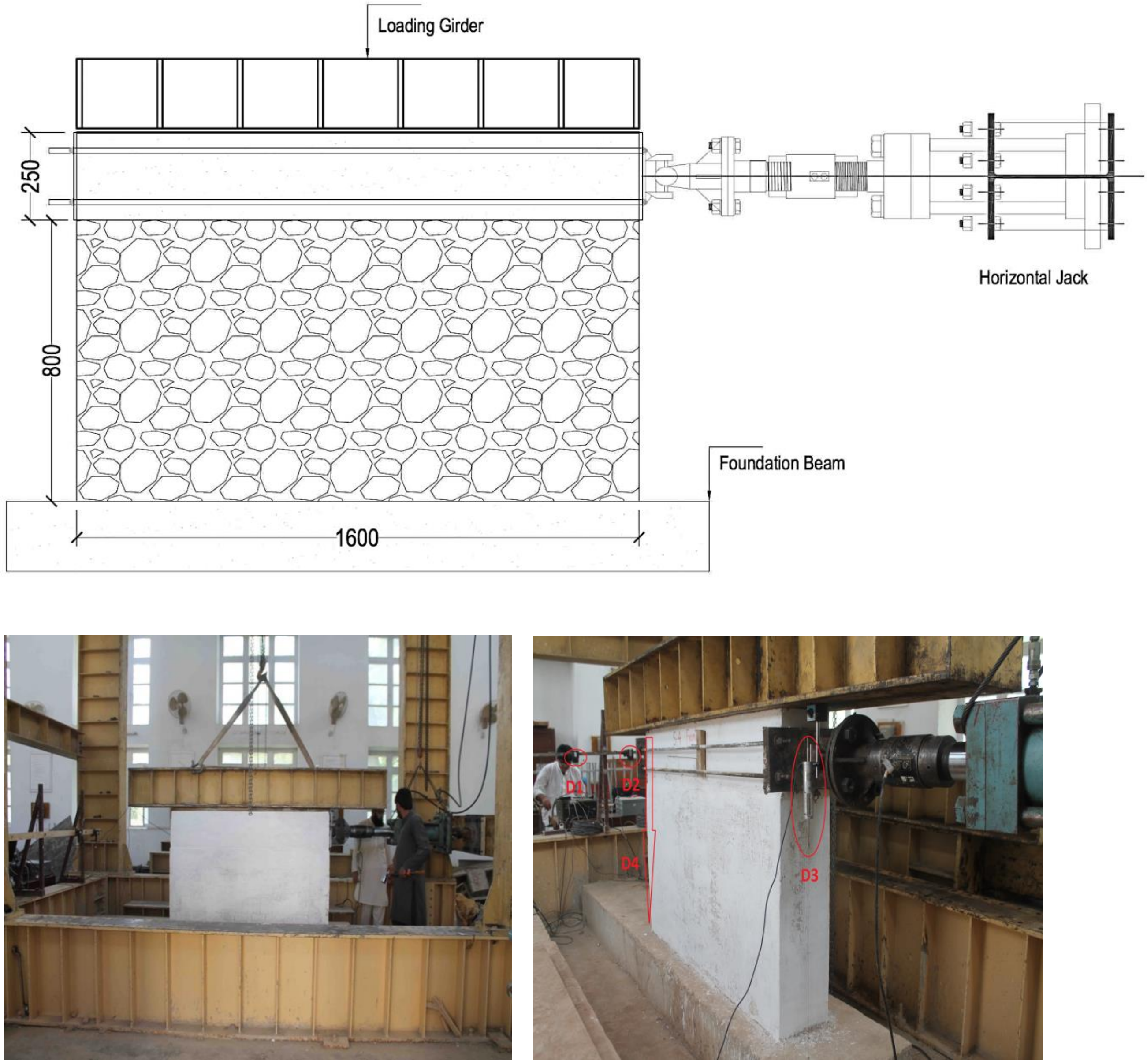


Figure 33: Test setup for in-plane quasi-static cyclic tests on masonry piers (pier thickness scaled to 2/3rd of the prototype)

Figure 34 to 38 reports the hysteretic behavior and force-displacement response of the stone walls, bi-linear idealization and damping for stone masonry, while figure 41 to 45 reports the same for CSEB respectively. In case of stone masonry, Sample 1, 2 and 3 are in unstabilized mud mortar with wire containment while sample 4 is in unstabilized mud mortar only. Also, in case of CSEB, both the samples are in cement stabilized mud mortar. Furthermore, the hysteretic curves were analyzed to calculate the dissipating energy per cycle (Ed), the elastic stored input energy (Ei) and, the hysteretic damping.

$$x_{hyst} = \frac{Ed}{2pEi}$$

where E_d is the dissipated energy per cycle, E_i is the input stored energy.

Figure 39 and Figure 40 shows the damage evolution of stone masonry walls; with and without containment, subjected to in-plane loading. Under smaller lateral displacement, only few slight cracks were observed in plaster, which increased spatially upon subjecting wall to large displacement resulting in the spalling of plaster. The wall compressed vertically, and the individual stone units experienced sliding under lateral load. For specimen with wire containment, the wall distortion stressed the containment wires in tension, providing capacity against lateral loading. The alternate tension-compression and vertical settlement of stones to get packed, resulted in to the buckling of wires. However, the containment kept the stones in cage and didn't allow the partial and total collapse of wall. Due to vertical settlement under large displacement, wall with containment was observed with little out-of-plane bulging, however, stone dislocation and stone sliding was observed in wall without containment.

Wall without containment was observed with horizontal crack at the top beam bottom level and roughly diagonal cracks. The diagonal cracks width increased with increasing lateral displacement demand that resulted into separation of wedge like portion from masonry walls on both left and right top ends. The wall was also observed with out-of-plane bulging and sliding of stones and the specimen was found in incipient collapse state. Table 19 reports the mechanical properties calculated for stone masonry walls.

Figure 46 and 47 shows the damage evolution of the CSEB wall specimen, subjected to in-plane loading. In case of wall S1, under smaller lateral displacement cycles, clear diagonal cracks were observed on both diagonals, which aggravated upon subjecting wall to large displacement resulting in severe diagonal shear cracking along the mortar joints.

Table 19: Stone Masonry wall in-plane response parameters

S. No	Description	Unstabilized mud mortar with surface containment					Unstabilized mud mortar without surface containment
		Sample 1	Sample 2	Sample 3	Avg.	CoV (%)	Sample 4
1	Lateral Strength, kN	11.4	11.9	13.5	12.26	8.94	8.7
2	Lateral Stiffness, kN/mm	2.53	5.3	3.30	3.71	38.53	8.78
3	Yield Drift (%)	0.45	0.26	0.4	0.35	28.13	0.10
4	Ultimate Drift (%)	3.20	2.54	2.95	2.9	11.49	1.8
5	Ductility Ratio	7.11	9.66	7.37	8.04	17.45	18.18
6	Damping at Yielding (%)	15.0	20.0	20.0	18.33	15.74	25.0

Note: As expected large variation in results in masonry construction, the results of Sample 4 cannot be considered reliable enough because of limited number of tested samples.

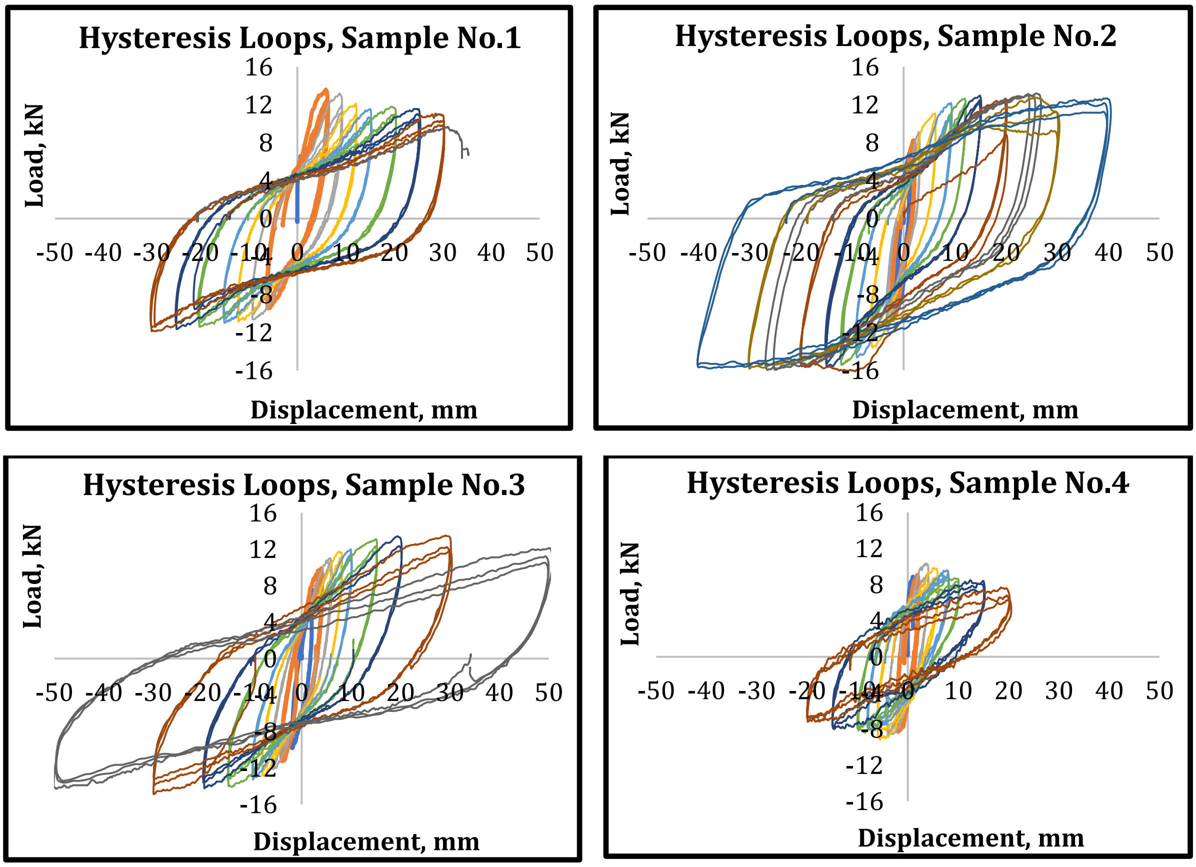


Figure 34: Force-Deformation Hysteresis Loops for stone masonry (Sample 1-3 unstabilized mud mortar with surface containment, sample 4 unstabilized mud mortar without containment)

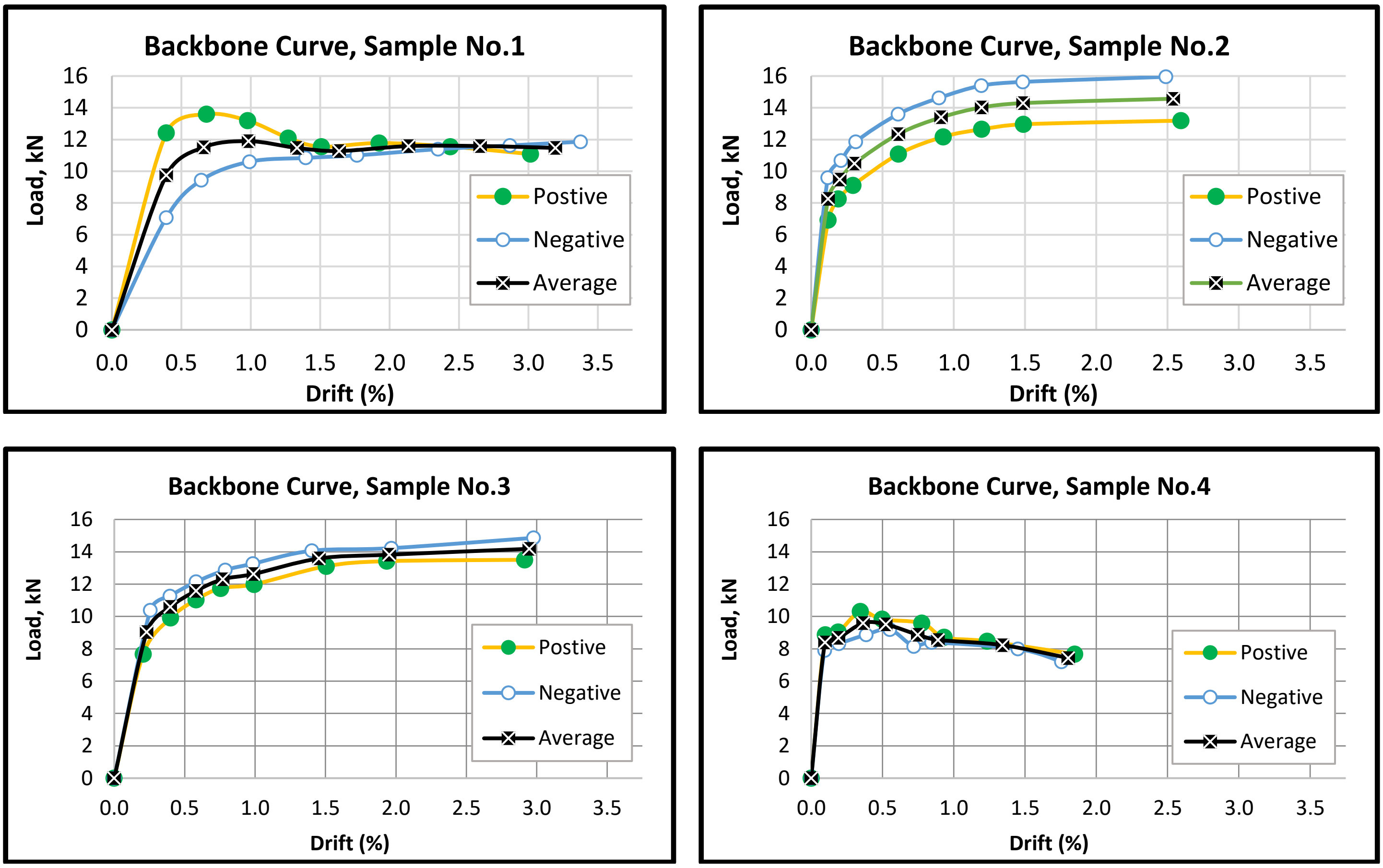


Figure 35: Force-displacement backbone curves for stone masonry

Note: It is worth mentioning that stone masonry piers with containment exhibited significant sliding after damage. For calculating pier ductility and R-Factors, very large deformations (approximately above 3%) due to sliding have been ignored.

Initially, shear sliding along the crack path was observed, which was followed by rocking of the specimen wedges. A large wedge was about to separate from the left/right sides of wall under imposed displacement of 10 mm. In case of Wall S2, under smaller lateral displacement cycles, horizontal cracks appeared few courses above the toe at both corners. Clear horizontal bed-joint cracks were formed and the wall started sliding over the bed-joint surface. Masonry below the sliding surface exhibited multiple cracks and was subjected to toe crushing due to uplifting of sliding (rocking) wall portion at both the corner. Corner splitting and wedge separation was observed under large displacement cycles. Table 20 reports the mechanical properties calculated for CSEB masonry walls.

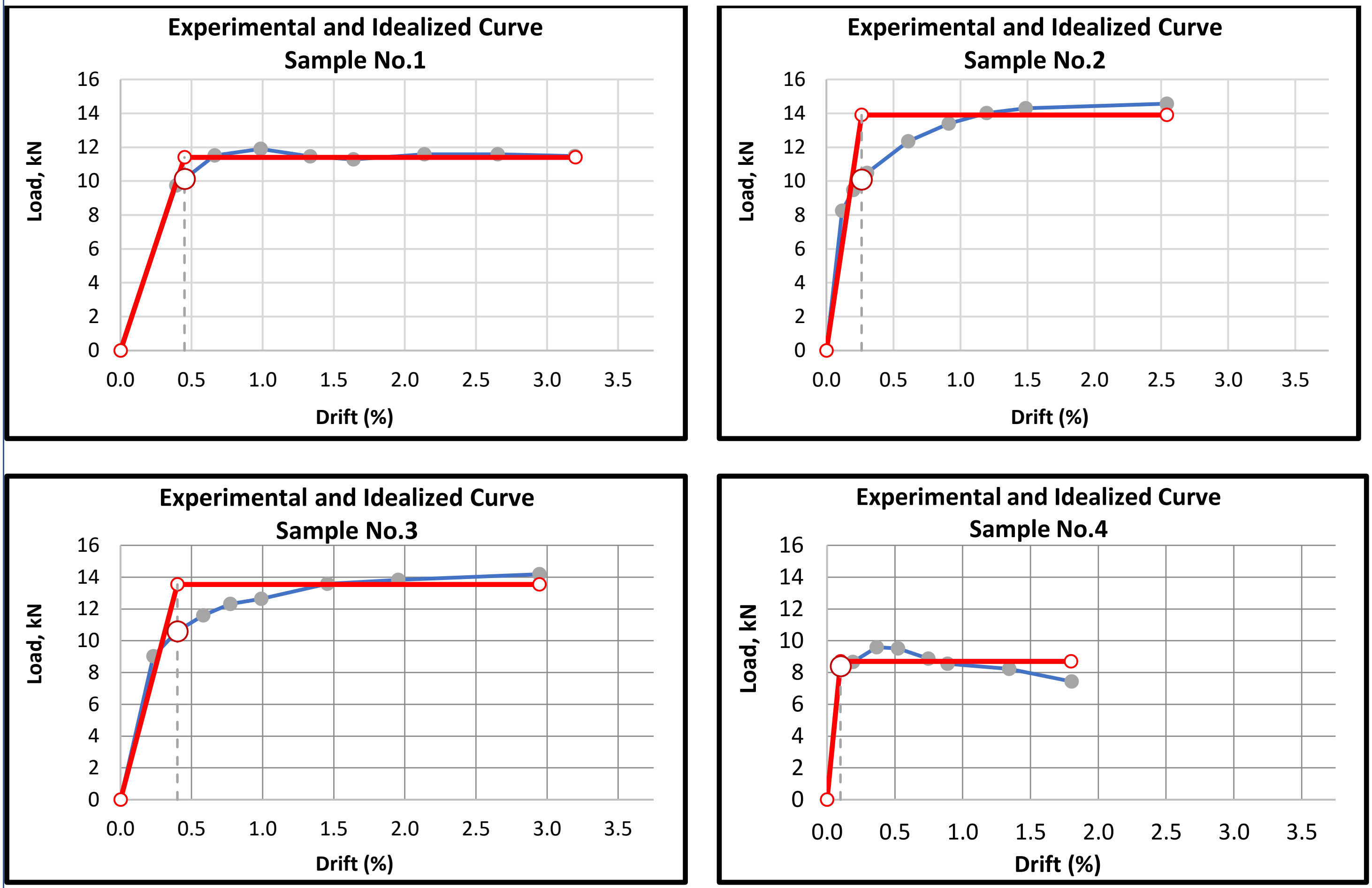


Figure 36: Bi-linear idealized force deformation capacity curves for stone masonry

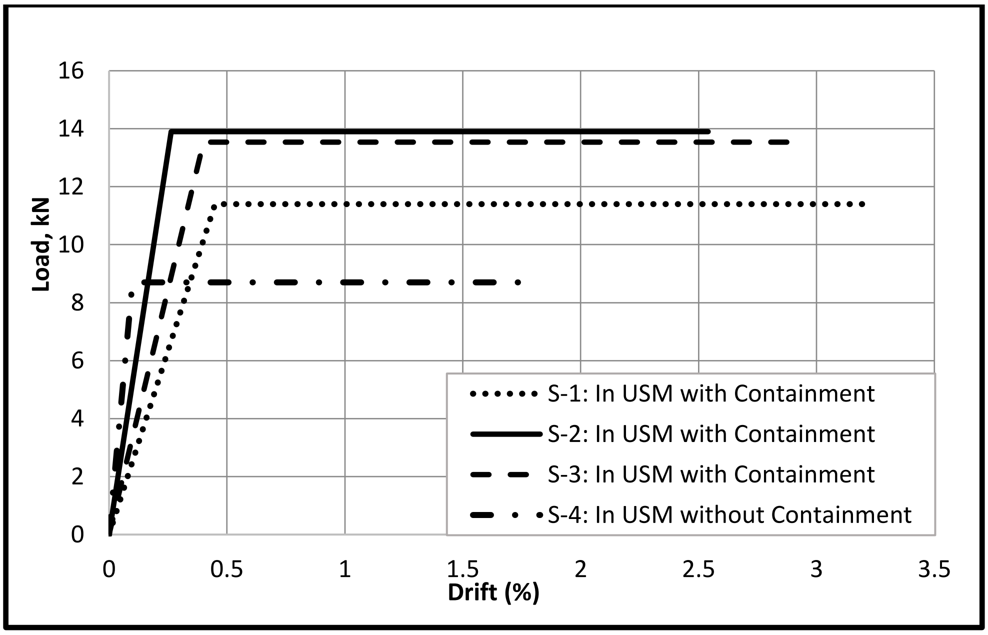


Figure 37: Combined bi-linearized capacity curves for Stone Masonry

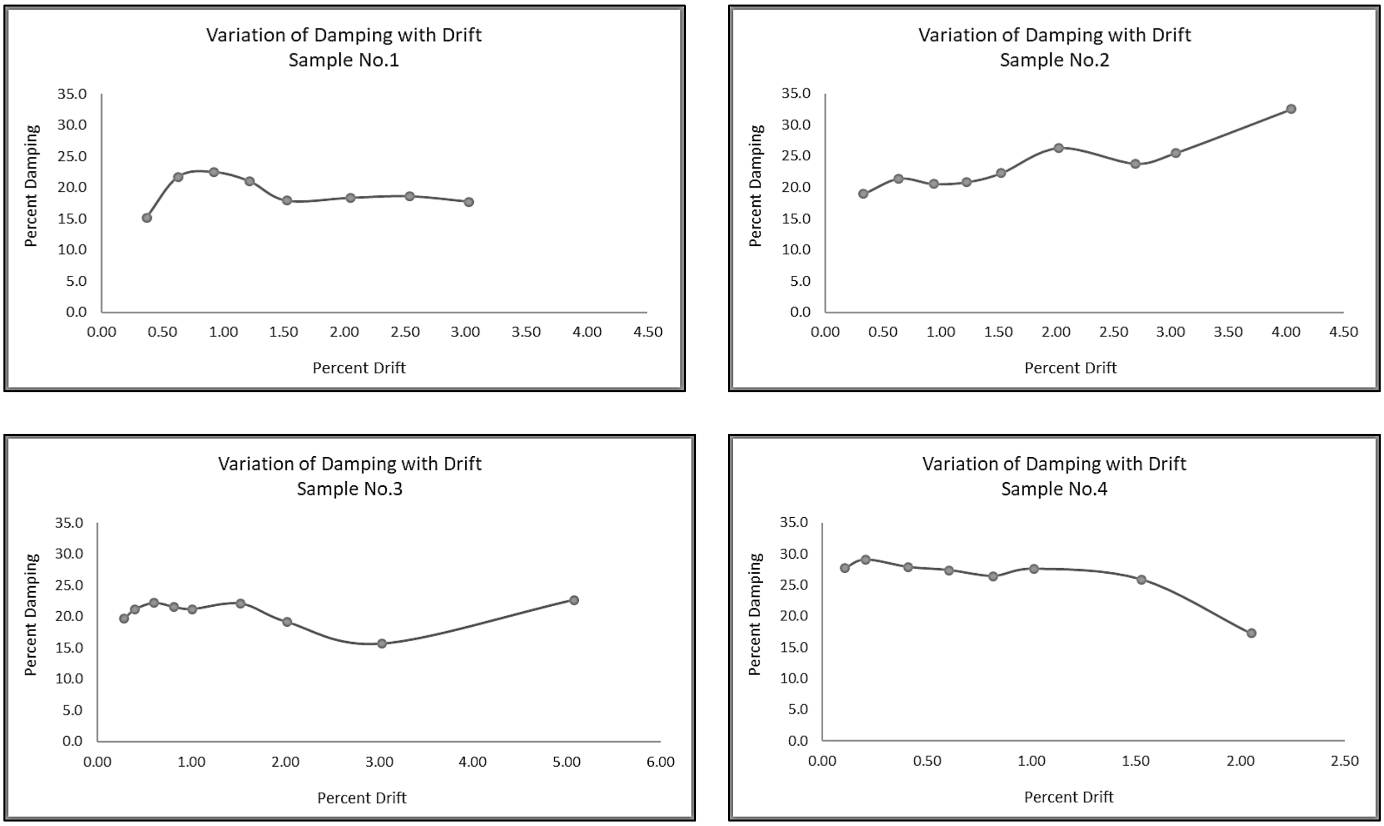


__Figure 38: Variation of hysteretic damping of stone masonry pier with drift__

__Table 20: CSEB Masonry wall in-plane response parameters__

S. No	Description	Sample 1	Sample 2	Average	CoV (%)
1	Lateral Strength, kN	7.0	11.0	9.0	31.42
2	Lateral Stiffness, kN/mm	7.0	15.7	11.35	54.20
3	Yield Drift (%)	0.107	0.068	0.09	30.64
4	Ultimate Drift (%)	0.61	1.01	1.04	27.19
5	Ductility Ratio	5.71	14.86	12.50	51.76
6	Damping at Yielding (%)	35.0	40.0	37.5	9.42

Figure 39: Damage evolution of the stone masonry wall under in-plane quasi-static cyclic load - No Containment

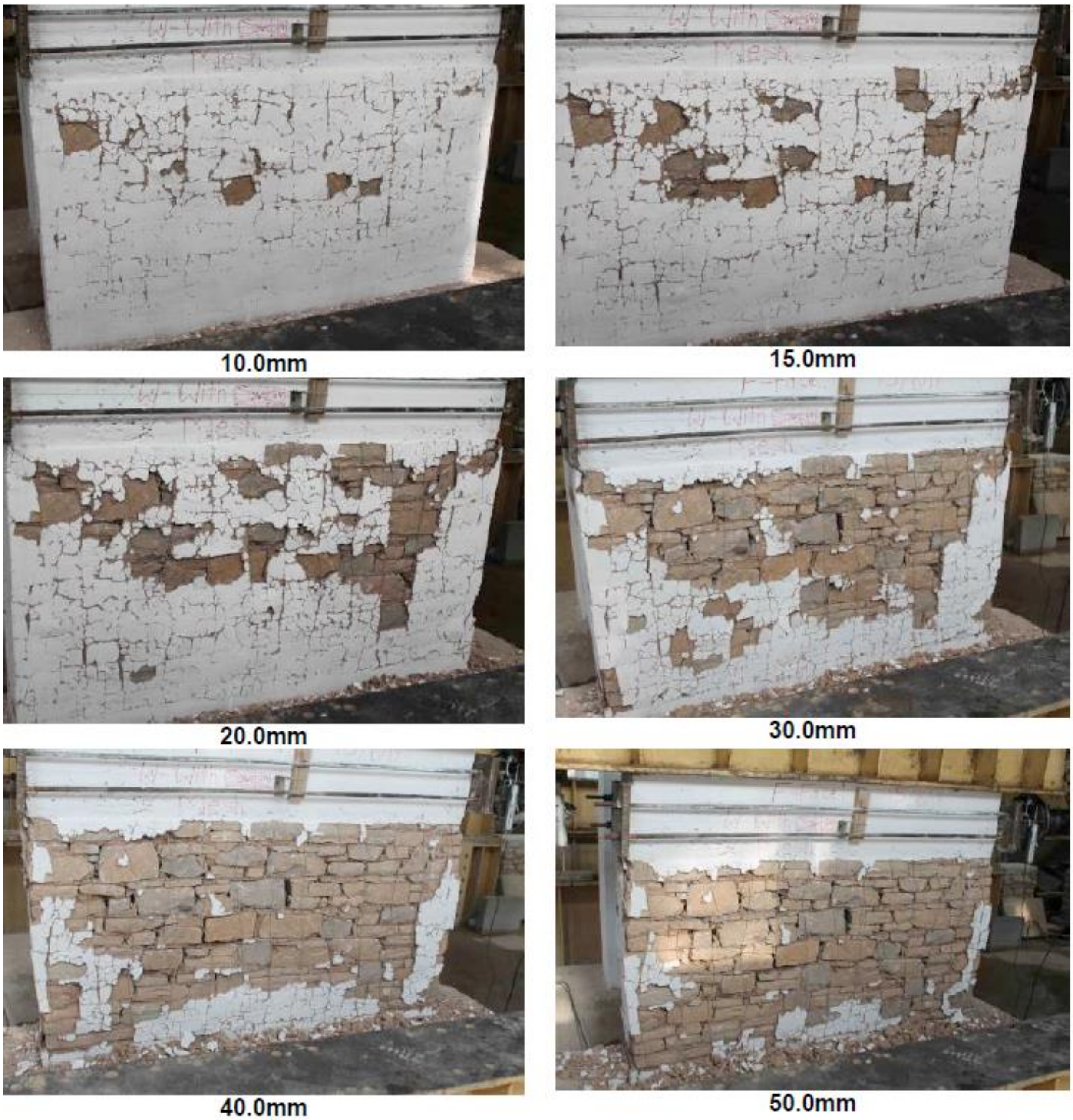


Figure 40: Damage evolution of the stone masonry wall under in-plane quasi-static cyclic load – Containment (Sample no. 2)

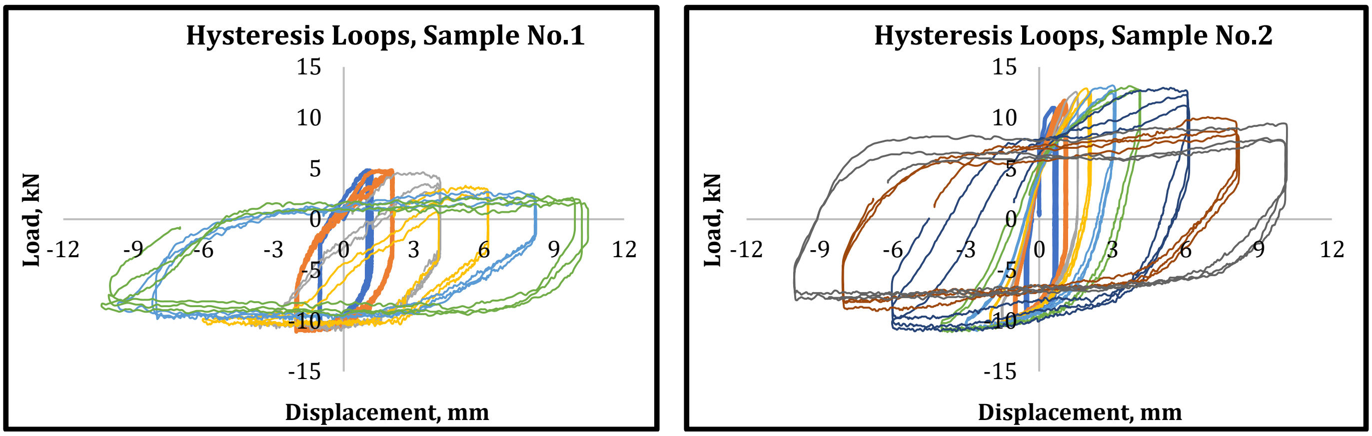


Figure 41: Force-Deformation Hysteresis Loops of CSEB masonry

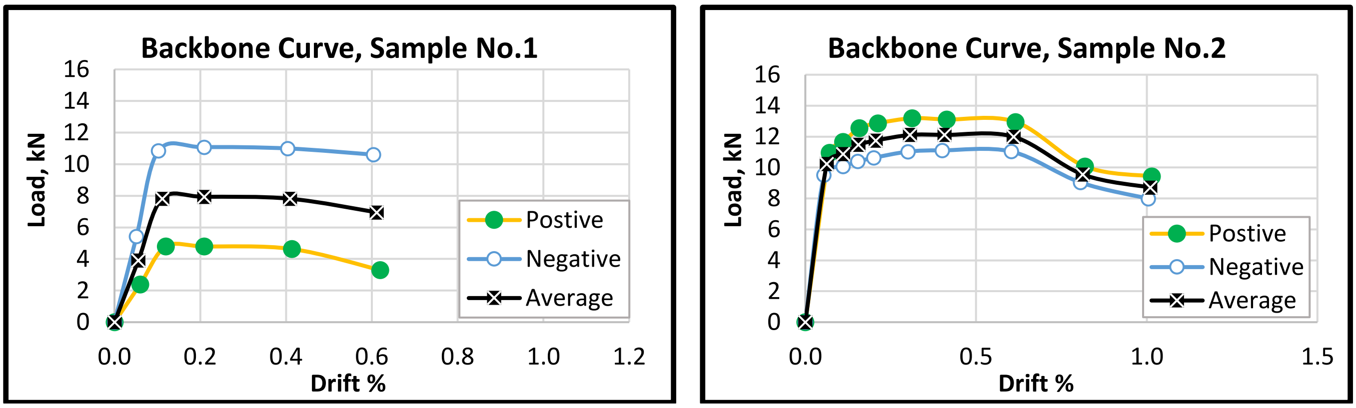


Figure 42: Force-displacement backbone curves for CSEB masonry

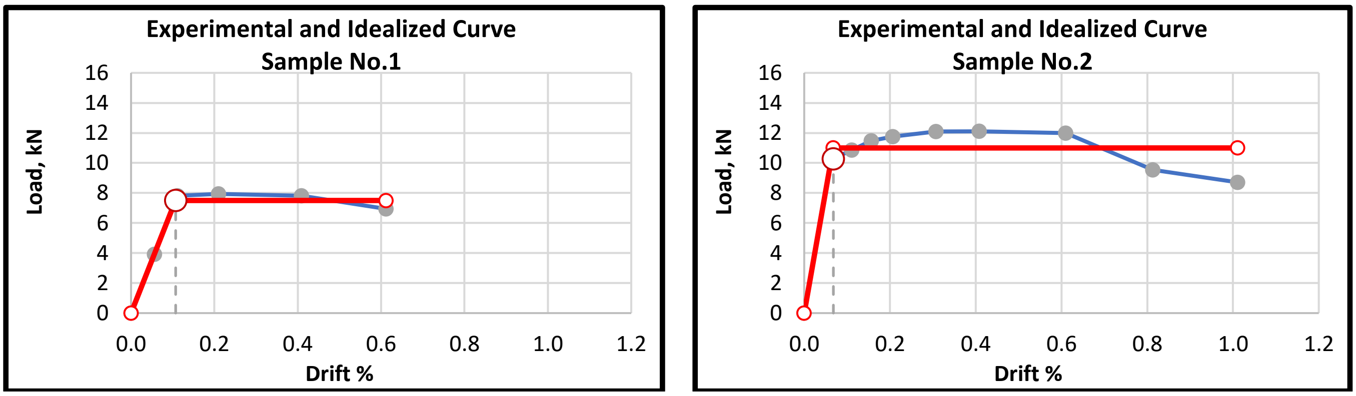


Figure 43: Experimental backbone and bi-linear idealization for CSEB masonry

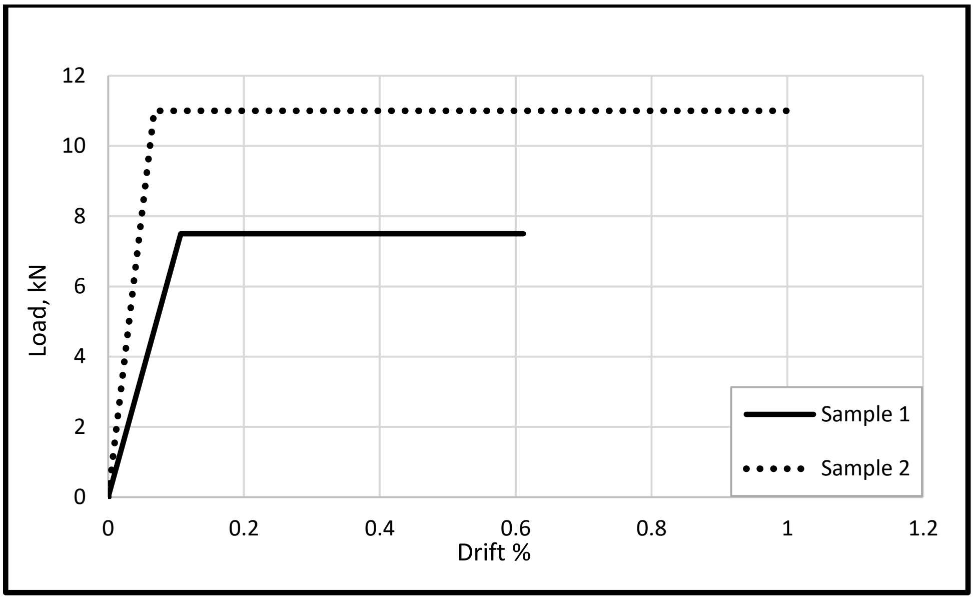
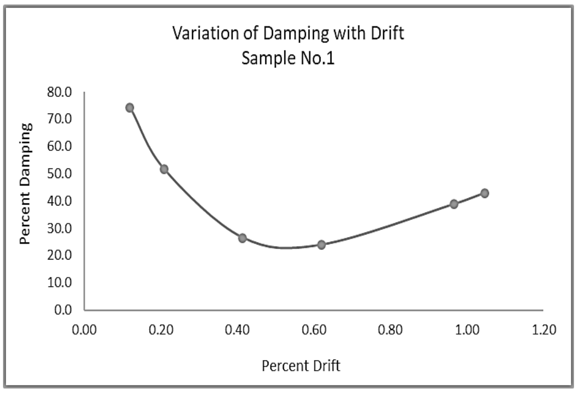


Figure 44: Combined bi-linear idealized capacity curves for CSEB Masonry



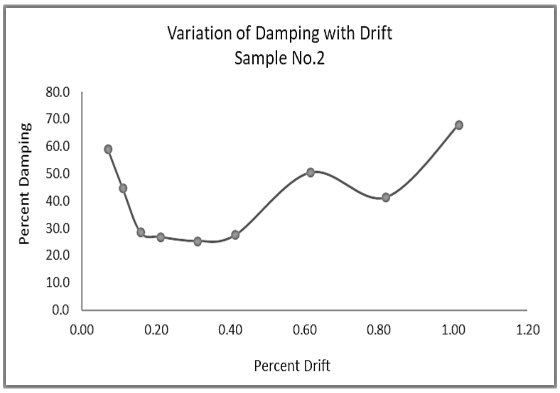


Figure 45: Variation of hysteretic damping of CSEB masonry pier with drift

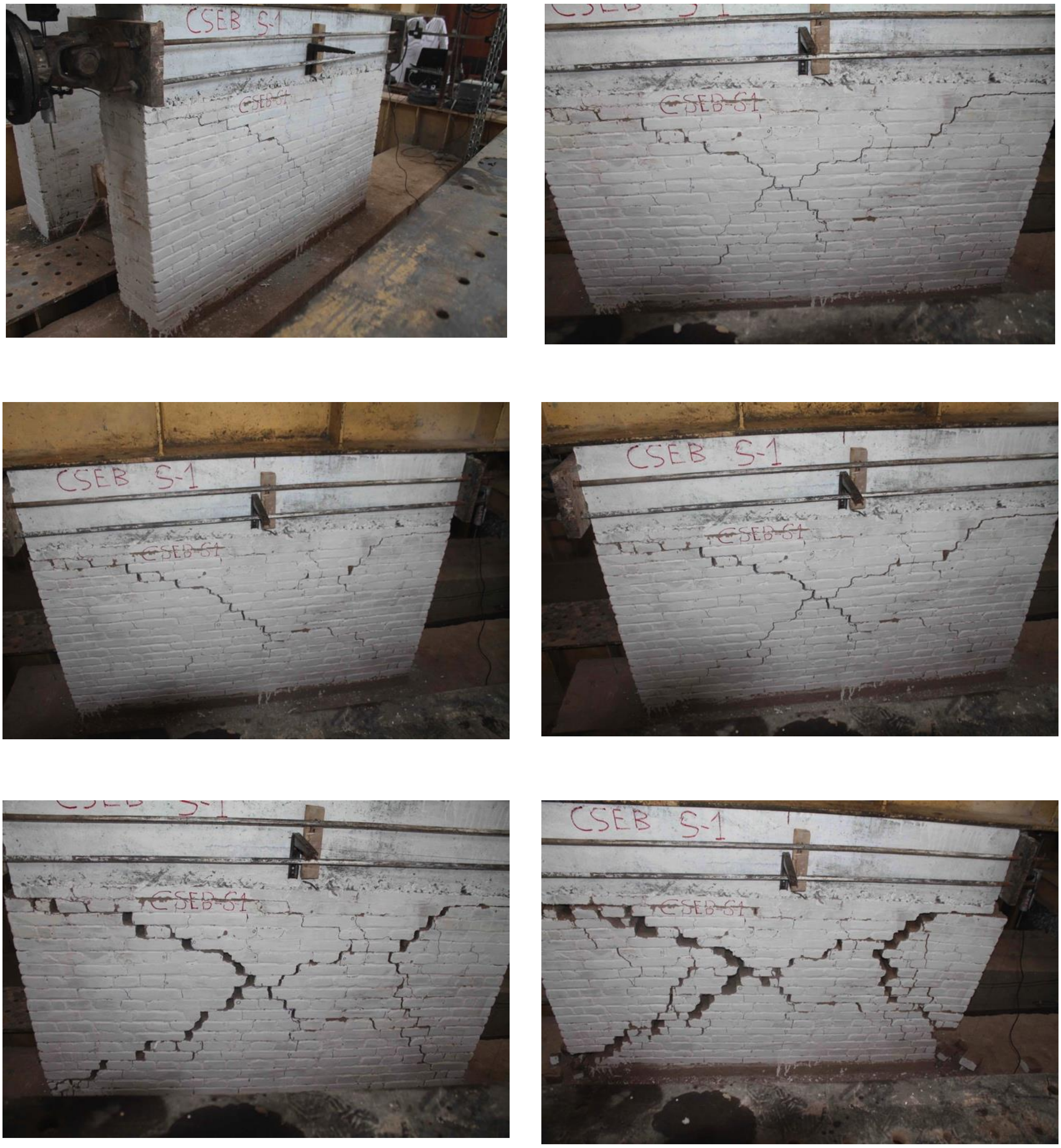


Figure 46: Damage evolution of the CSEB wall under in-plane quasi-static cyclic load-Wall S1

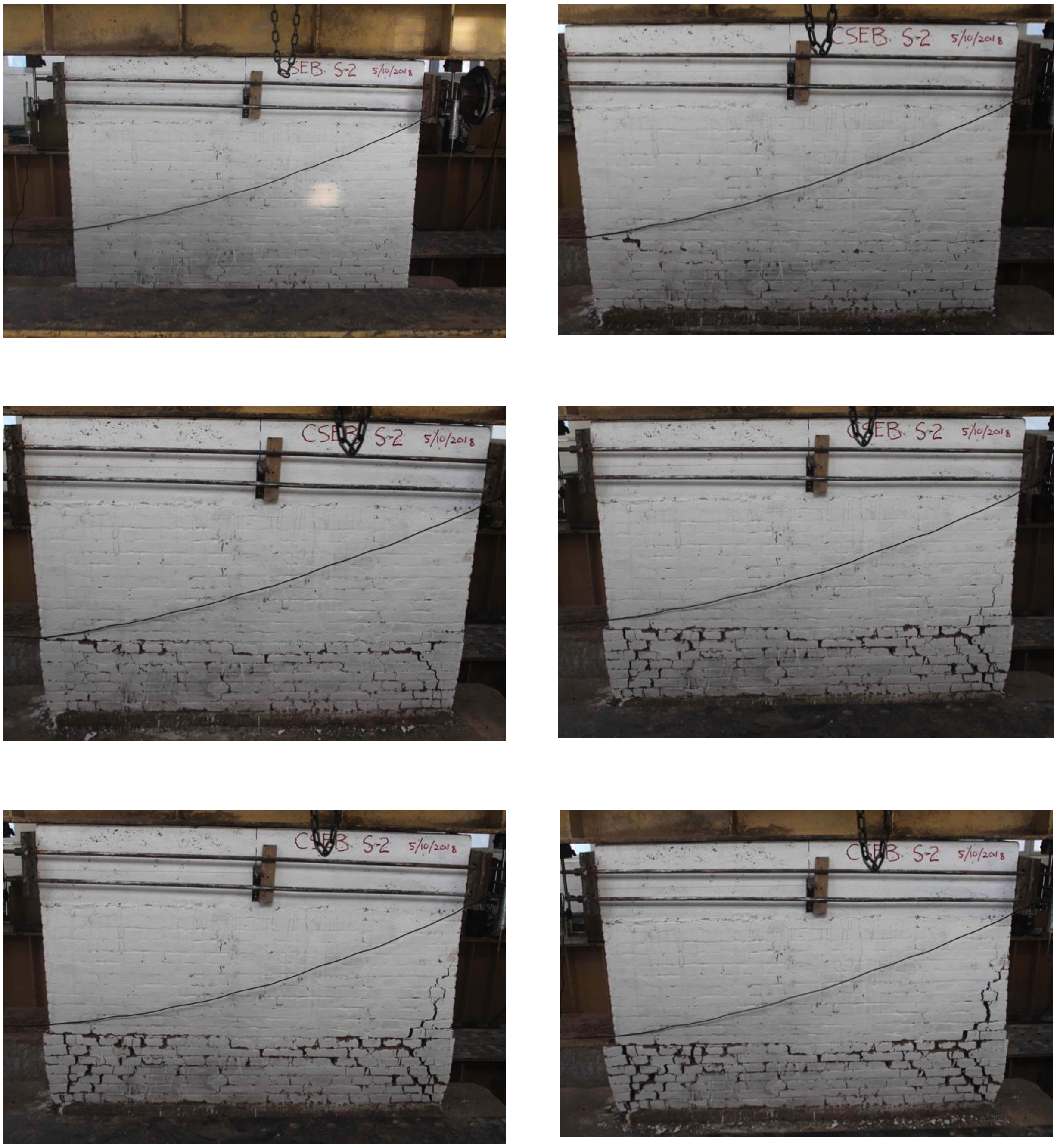


Figure 47: Damage evolution of the CSEB wall under in-plane quasi-static cyclic load-Wall S2

CHAPTER 5: EXPERIMENTAL PROGRAM – SHAKE TABLE TESTS

5.1 Test Models Construction

The model buildings were constructed with the same materials as that of the idealized prototype. For the shake table test models, all the prototype buildings' geometry and its elements including wire diameters were linearly reduced to 1/3rd and 2/3rd size of the prototype, respectively. In case of unavailability of exact dimensions, for example that of wires for containment, the necessary conservative approximations were carried out. The stones/bricks were also scaled down to 1/3rd and 2/3rd scale to suit scaled model buildings so the number of bedding plane remains same to that of the prototypes. The reduced scale CSEB units were made in the laboratory. Model Type Design 1 and Type Design 3 were constructed in cement stabilized mud mortar, while Type Design 2 and Type Design 4 were constructed using unstabilized mud mortar. The vertical containment wires (in case of Type Design 1, Type Design 2 and Type Design 4) were not anchored into the base slab, however, vertical rebars used in case of Type 1 and Type 3 models were anchored to the base using epoxy. It is worth mentioning that welded wire mesh (WWM) was used in case of 2/3rd model of Type Design 1 while wires were used in all other cases. The roof was constructed of corrugated iron sheets supported by timber trusses. The model buildings were provided with the earthquake resistant elements including surface containment mesh (Type Design 1, Type Design 2 and Type Design 4) as discussed earlier. Attempts were made to simulate the field conditions of the earthquake-affected areas of Nepal while constructing the test model buildings. To simulate the field conditions, quality control of the construction materials and skills was kept to a minimum. The model buildings were mud plastered (except Type Design 3) and whitewashed, so the cracks could be visible during the testing. The 2/3rd and 1/3rd scale model buildings were tested on

60 ton (large shake table) and 8 ton (small shake table) payload capacity shake tables, respectively.

5.1.1 2/3rd Scaled Model Building (Large Shake Table Tests)

The 2/3rd scaling of the proposed prototype resulted in model building of size for stone masonry: 5.08m (L)×3.94m (B)×2.64m (H) and for CSEB masonry: 5.08m (L)×3.94m (B)×2.53m (H), including roof space, but excluding buttresses. Appendix C1 (Type Design 1), Appendix C2 (Type Design 2), Appendix C3 (Type Design 3) and Appendix C4 (Type Design 4) presents details of the actual 2/3rd scale model building prepared for shake table testing. Figure 48, 50, 52 and 54 depicts images from the laboratory site, at various stages of 2/3rd scale model construction.

5.1.2 1/3rd Scaled Model Building (Small Shake Table Tests)

The 1/3rd scaling of the proposed prototype resulted in size for stone masonry: 2.54m (L)×1.97m (B)×1.32m (H) and CSEB masonry: 2.54m (L)×1.97m (B)×1.27m (H), including roof space, but excluding buttresses. Appendix D1 (Type Design 1), Appendix D2 (Type Design 2), Appendix D3 (Type Design 3) and Appendix D4 (Type Design 4) shows details of the actual 1/3rd scale test model prepared for shake table testing. Figure 49, 51, 53 and 55 depicts images from the laboratory site, at various stages of 1/3rd scale model construction.

Before dismantling of 1/3rd scale Type Design 1, the model was also tested after the removal of 50% and 100% wall surface containment mesh from the in-plane walls. Similarly, 1/3rd scale Type Design 2 model was also tested after the removal of 50% and 100% wall surface containment mesh from both the in-plane and out-of-plane walls.

To understand performance of repaired models, the 1/3rd scale Type Design 2 and 3, and 2/3rd scale Type Design 3 were also tested on the shake table after cosmetic repair. These models were tested in the transverse direction. The 1/3rd scale Type Design 3 model was also tested in the longitudinal direction (without any further repair) after testing it in the transverse direction. Due to time limitation, the data obtained from the tests conducted on repaired models were not analyzed for calculating response parameters, but their observed damage behavior is discussed in this report.

Figure 48: Construction stages of 2/3rd Scale Model Building of Type Design 1

Figure 49: Construction stages of 1/3rd Scale Model Building of Type Design 1

Figure 50: Construction stages of 2/3rd Scale Model Building of Type Design 2

Figure 51: Construction stages of 1/3rd Scale Model Building of Type Design 2

Figure 52: Construction stages of 2/3rd Scale Model Building of Type Design 3

Figure 53: Construction stages of 1/3rd Scale Model Building of Type Design 3

Figure 54: Construction stages of 2/3rd Scale Model Building of Type Design 4

Figure 55: Construction stages of 1/3rd Scale Model Building of Type Design 4

5.2 Input Motions and Testing Protocols

Both 1/3rd and 2/3rd test models were shaken in the transverse direction considering high vulnerability of the long walls under face load. In addition to this, there is almost similar total length of in-plane walls and piers in both directions of the model. The model buildings were subjected to increasing intensity of excitation (i.e. PGA). To track softening of the model buildings, the buildings were subjected to free vibration after each episode of significant excitation. After every run, the models were inspected for possible damages, which were recorded/documented in the form of visual observations, still photographs and continuous recording through cameras (CCTV and DSLRs).

The 1/3rd scale Type Design 2 and Type Design 3 were also tested after cosmetic repair subjecting them to the same protocol as that of the virgin model. Follow-up of this, the 1/3rd scale Type Design 3 model was also tested in the longitudinal direction.

5.2.1 2/3rd Scaled Models (Large Shake Table Tests)

These models were tested under sinusoidal base excitation of varying frequency and base imposed displacement, employing the 60-Ton large shake table. The input frequencies were varied between 2 Hz to 12 Hz (2-to-12 Hz and then 12-to-2 Hz) and the base target displacement were selected based on the pseudo relationship, varying from 1.5mm to maximum displacement, calculated not to exceed the base acceleration more than 1.0g, which is the maximum acceleration limit of the seismic simulator. Refer to Appendix G1 (Type Design 1), Appendix G2 (Type Design 2), Appendix G3 (Type Design 3) and Appendix G4 (Type Design 4), for corresponding specified frequency and table displacements. A number of runs (refer to Appendix G1, G2, G3, and G4 for testing protocol) were carried out, considering different combinations of input frequency and base target displacement, and additional free vibration tests after significant runs.

The 2/3rd scale Type Design 3 model was tested after repair and subjected to the same shaking protocols as that of the virgin model.

The models were instrumented with accelerometers and displacement transducers to record the structure acceleration and displacement response under the lateral vibrations. Appendix E1 (Type Design 1), Appendix E2 (Type Design 2), Appendix E3 (Type Design 3) and Appendix E4 (Type Design 4) shows the instrumentation plans adopted herein.

5.2.2 1/3rd Scaled Models (Small Shake Table Tests)

The 1/3rd scale models were tested on 8-Ton small shake table, seismic simulator. These models were tested under earthquake acceleration record, which included: (i) acceleration time history of the Northridge (USA) earthquake of 17th January 1994 recorded at 090 CDMG STATION 24278. The acceleration time history was matched to the code specified design acceleration spectrum (IS 1893) (Refer Figure 56). The 1/3rd scale models (Type Design 2 and 3) were also tested on the shake table after cosmetic repair and were subjected to the same testing protocol to which the virgin model was subjected to. Additionally, the models were tested on KIRT_EW time history. The repaired model of Type Design 3 was also tested in the longitudinal direction after testing it in the transverse direction.

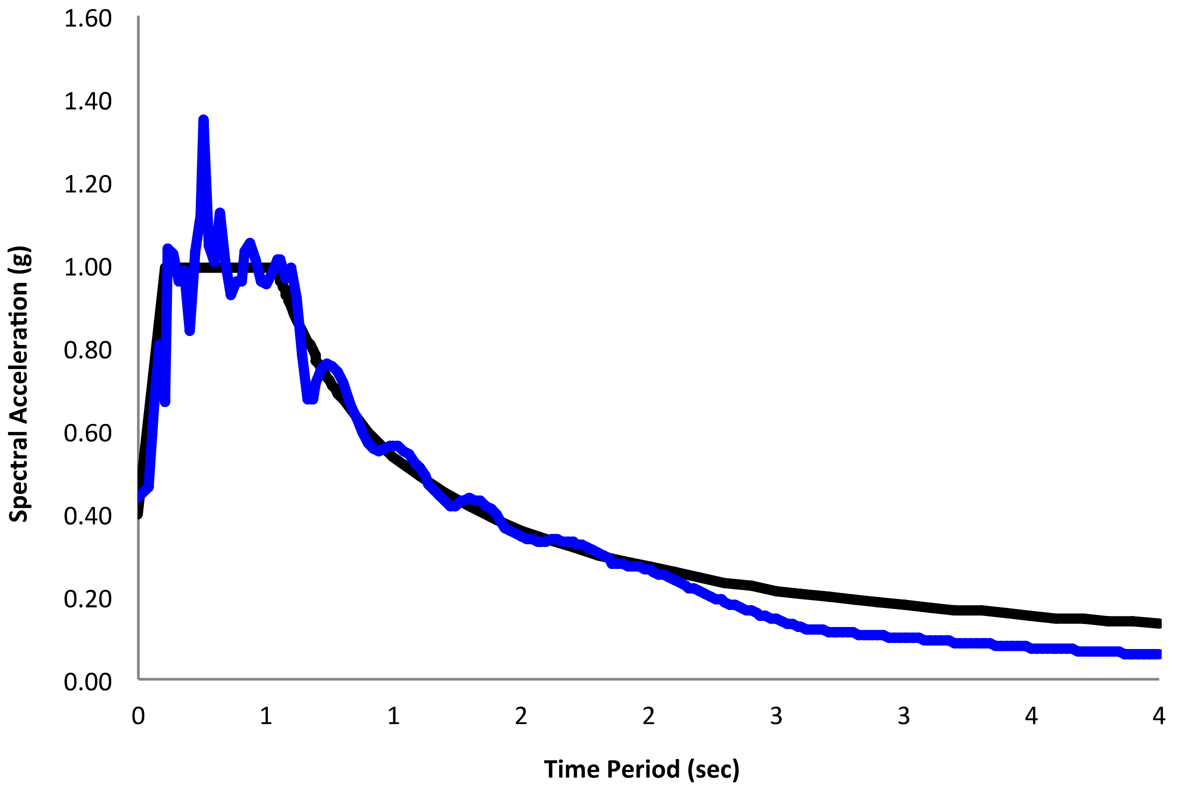


Figure 56: Compatibility of acceleration record spectrum and code specified elastic respomse spectrum

To meet the scaling requirements (Bothara et al., 2010; Tomazevic, 2000), the acceleration time history frequency was increased by Scale Factor$^{0.5}$ = $3^{0.5}$ in the present case. Two sets of acceleration records were prepared; EQ1, matched to design spectrum and EQ2 scaled to 1.0g, which was 240% of the design spectrum represented rare earthquake shaking. The models were subjected to multiple excitation of EQ1, linearly scaled from 5% to 100%. Similarly, the models were subjected to EQ2, linearly scaled from 60% to 100%. Appendix F1 (Type 1),

Appendix F2 (Type 2), Appendix F3 (Type 3) and Appendix F4 (Type 4) shows the instrumentation plans for 1/3rd scale test model. Testing protocol is presented in Appendix I1 (Type 1), Appendix I2 (Type 2), Appendix I3 (Type 3) and Appendix I4 (Type 4).

5.3 Observed Behavior of Tested Models

5.3.1 Type Design 1

General

Both the 2/3rd and 1/3rd models behaved very similar under subjected input base excitations. Under low and moderate shaking, the models didn't show any significant/visible damages in structural or non-structural components. Very few cracks were appeared in the plaster of walls under moderate to strong shaking, and some spalling of plaster was observed. Under very extreme shaking, the model showed significant sliding and rocking of stones in the in-plane wall panels due to in-plane forces and induced lateral displacement. However, the containment wires ensured integrity of walls which allowed re-centering of the building with no significant distress in walls (permanent deformation). The deformation in the structure, clearly observed even visually, were well distributed over the whole area of wall panels. The out-of-plane walls were subjected to global rocking, with respect to the base, like a continuum body due to the bands, wire mesh containment and buttresses. No any damage was observed in the out-of-plane walls, except slight cracks over large area of walls, and a few spalling of plaster at the toe of buttresses. Tremendous energy dissipation capacity has been observed in the model, which is due to well distributed cracks in walls, horizontal sliding and rocking of stones at multiple locations in the in-plane wall panels. The model was even capable to resist acceleration of 1.0g, with no collapse/delamination of stones and no major damage to walls.

The design scheme is capable to resist future design level earthquakes without any collapse or major damages that could endanger the occupant's lives during the earthquake event.

2/3rd Scale Model

The test model was not observed with any visible cracking or damage during excitations having frequency of 2 Hz. Similarly, no damage was observed during excitations having frequency of 4 Hz and table-imposed displacement of 3mm or below.

Under base excitation of 4 Hz and table-imposed displacement of 6mm, the test model was observed with horizontal cracking to in-plane Wall 4, just below the eave band. The same wall was also observed with minor plaster spalling. For the same input frequency (4 Hz), increasing the table-imposed displacement to 12 mm, the extent of damage to model increased. The existing cracks on Wall 4 further widened and more spalling of plaster was observed. Similar to Wall 4, Wall 3 was also observed with horizontal crack at the eave band level. Out of plane wall (Wall 1) was observed with rocking at the base of buttress. Further, Wall 1 was observed with slight horizontal cracking just below the eave band level. Minor spalling of plaster was also observed. This run seemed to have vibrated the model around its predominant frequency.

On further increasing the base input frequency from 6 Hz to 12 Hz, with varying amplitudes of table-imposed displacement, didn’t cause any further significant damage, except the widening of existing cracks and spalling of plaster. The high frequency excitation induced localized multiple vibrations of stone units on walls.

The low frequency excitation at 4 Hz was repeated with imposed table displacement of 12 mm with total duration of 20 sec. The excitation proved to be the intense shaking for the test model, causing violent vibration of the model. Under this run, toe crushing of buttress (movement of stones) on Wall 2 was observed. Crushing and spalling of concrete from splint at the corner of the building, junction of Wall 4 and Wall 2, was observed. The longitudinal re-bar was visible at the base and observed to have buckled. Cracks and damage were distributed over large area of walls, indicting significant energy dissipation of the model. Despite the intense shaking and long duration of excitation, the model was able to resist the lateral loads without collapsing or exhibiting any serious damage. Appendix G1 reports all the test runs with respective observed damages while Appendix H1 reports observed damages under significant runs.

1/3rd Scale Model

The model under design base earthquake EQ1 was not observed with any significant damage except minor horizontal cracking in the in-plane walls.

Under EQ2 90% test run, the test model was observed with toe crushing (delamination of stones) of buttress on face-loaded wall W1. The existing cracks in the in-plane walls further widened. Under 100% test run, the model vibrated violently that increased the severity of cracks in the models. The model was also observed with spalling of plaster from walls at various locations. After the model softening, EQ2 was repeated, the existing damage in the model further aggravated. Toe crushing (delamination of stones) on in-plane was also observed. Both the in-plane walls were observed with significant plaster spalling.

The model surface containment was reduced by 50% in wall 3 and by 100% in wall 4 for further runs. EQ 2 runs were repeated, the model under 70% run was observed with falling of few stone units from the in-plane walls. In-plane walls were observed with severe sliding of bands. Under 100% run, wall 4 was observed with significant falling of stone units. Appendix I1 reports all the test runs with respective observed damages while Appendix J1 reports observed damages under significant runs.

5.3.2 Type Design 2

General

Both the 2/3rd and 1/3rd scale model buildings behaved very similar under subjected input base excitations. However, in general the 2/3rd scale model suffered more damage than the 1/3rd scale model because of bi-directional loading (the shaking of the table platform was little eccentric), although the damage patterns were very similar. Under low and moderate shaking, the model buildings didn't show any significant/visible damages to structural or non-structural components other than slight cracks at the base of the long walls and buttresses. Under moderate to strong shaking, the models were observed with a few plaster spalling particularly at the base levels (between plinth and sill level at buttress) and between sill and lintel level over walls. This Type Design 2 model didn't show any horizontal sliding of gabion bands at any level, which is due to the homogenous nature of gabion band and walling materials interconnectivity of gabion stones with wall courses. The models were observed with significant rocking of the face-loaded walls (front wall W1 and rear wall W2), with horizontal sliding of masonry at their bases over in-plane walls (W4 and W3) at very strong shaking. The observed behavior of Type Design - 2 indicates that it was relatively more flexible, particularly the out-of-plane walls, than Type Design - 1.

2/3rd Scale Model

Under base excitation of 2 Hz frequency and imposed base displacement of 24 mm, the model was observed with flexural cracking of buttress with distributed horizontal cracks at the base, with some minor damage to plaster.

Under base excitation of 4 Hz frequency and imposed base displacement of 3 mm, local out-of-plane vibration of W1 was observed at lintel level. Further increase in base imposed displacement up to 6 mm caused resonance of the building with significant rocking of buttresses and out-of-plane walls (W1 and W2). Plaster spalling from walls was observed in small chunks. Sagging of door/window lintel was observed due to movement of piece lintel. Cracking to in-plane wall (W4) was also observed. Further increasing imposed displacement up to 12 mm caused severe resonance of buildings i.e. rocking of buttresses and out-of-plane walls. Plaster spalling from walls and aggravation of cracks to in-plane wall (W4) were observed. Plaster spalling due to toe crushing at base of buttress (actually delamination of stones along the bottom masonry layers) was observed.

Increase in frequency up to 6 Hz and imposed displacement up to 6mm, caused plaster spalling and horizontal sliding of stones units. Reducing again frequency to 4 Hz while increasing imposed displacement up to 15 mm caused severe sliding of stones in out-of-plane walls. Rocking of walls and buttresses was observed. However, as the masonry units were well contained in the containment mesh, the walls remained stable.

The model was also tested under frequency of 3 Hz with imposed lateral base displacement of 20 mm, with intense shaking of 20 sec duration. This resulted in intense shaking of building with distributed rocking of face loaded walls and buttresses causing sliding of stones. But, no loss of masonry units was observed due to containment mesh.

Excitation of 4 Hz frequency and imposed displacement of 15 mm was repeated for a long duration of 20 sec. The model under this run was observed with severe sliding of stones but stones still contained in the wall surface containment mesh. Loosening of a roof truss anchor over out-of-plane wall was observed. Cracks on both out-of-plane and in-plane walls were aggravated with significant sliding of stones and wall bulging, however, these stones were basket by containment mesh and did not fall. However, few very small stone than the standard one fell off the walls. Appendix G2 reports all the test runs with respective observed damages while Appendix H2 presents photographic images of observed damages under significant runs.

1/3rd Scale Model

Under EQ1 shaking, the design level earthquake excitation, during the initial “self-check” of the shake table, the model was subjected to strong seismic excitation by the system than intended. This resulted in significant damage to the model. The model under this run was observed with out-of-plane rocking of buttresses of walls (W1, W2). Horizontal cracks were observed below the lintel on W1 and W2, propagating from door and window corners. As planned, the model was subjected to design level earthquake record (EQ1), with multiple intensities varying from 5% to 100% following the self-check of the table. However, no further notable damage was observed.

The model was then subjected to rare earthquake ground motion (EQ2) i.e. simulated through scaling design level earthquake to PGA of 1.0g. The model was first subjected to "self-check" before starting EQ2 shaking. Although not intended, under this run the model was again subjected to severe shaking due to the shake table malfunction. The model experienced significant out-of-plane rocking of long walls and buttresses, followed by horizontal sliding of model at the base. The existing cracks in walls further aggravated. Under 70% of EQ2, the model was observed with toe crushing of buttresses (actually delamination of stones along bottom layer of masonry) that was followed by plaster spalling because of toe crushing. Toe crushing followed by spalling of plaster was also observed on walls W1 and W2, near in-plane wall W3. Slight distributed cracks were also observed on W3. Toe crushing (actually delamination of stones along bottom layer of masonry) at base of buttresses and long walls (W1, W2) further aggravated under run of intensity 100% of EQ2, which was followed by further plaster spalling. Plaster spalling was also observed on W2 in small chunks from wall between lintel and eave level. Appendix I2 reports all the test runs with respective observed damages while Appendix J2 reports observed damages under significant runs. The model was not tested for KIRT-EW to save it for testing after repair.

This model was cosmetically repaired for retesting in order to see the performance of repaired model under the same testing protocol used for the virgin model. Under EQ1, the model was observed with slide cracking "mostly the appearance of previous cracks which were concede through mud plaster". The face loaded walls W1 and W2 of model were observed with minor rocking at the buttresses. Under EQ2, for intense shaking, the model was observed with significant rocking of out-of-plane walls W1 and W2 at buttresses. Toe crushing at the base of buttresses was observed which was followed by movement of stone units and push out of mortar. Plaster spalling at few locations was also observed. Damage at the wall to truss connection, particularly the end one, was also observed. The model was subjected then to KIRT_EW, under which significant rocking of the out-of-plane wall was observed. This caused heavy degradation of model and damage to spandrels.

For further runs, the wall surface containment was removed from in-plane wall W3 and out-of-plane wall W1 and W2 at their junctions with W3. Surface containment on half of the length of in-plane wall W3 and adjoining part of half of the length of W2 was reduced by 100%. Under intense shaking, extensive expulsion and movement of stone units from wall with no containment was observed. Damage to door spandrels aggravated and failure of connection between wall and truss connections was observed. Detailed description of observed damages under each run is reported in Appendix I2-R.

5.3.3 Type Design 3

General

Both the 2/3rd and 1/3rd scale model buildings behaved very similar under subjected input base excitations. However, in general the 2/3rd scale model suffered more damage than the 1/3rd scale model because of bi-directional loading (the shaking of the table platform was little eccentric), although the patterns were very similar. Under low intensity shaking, the model buildings didn’t show any significant/visible damages in structural or non-structural components other than slight cracks at the base of long walls and buttresses. Under moderate shaking, the models were observed with horizontal shear sliding cracks between sill and lintel level (mid-height) over wall 3 and wall 4. The models were observed with significant rocking of the face-loaded walls (front wall W1 and rear wall W2), followed by toe crushing of buttress of wall 1, and severe horizontal and diagonal shear cracking (sliding of masonry units along the mortar joint) of masonry over in-plane walls (wall 3 and wall 4), mostly between sill and lintel level piers. Corner damages and fall of brick units have been observed.

2/3rd Scale Model

Under base excitation of 4 Hz frequency and imposed base displacement of 6 mm, the model was observed with horizontal crack just below the lintel band on wall W2, due to out-of-plane rocking of wall panel. For the same frequency and imposed base displacement of 12 mm, horizontal cracks appeared on panels over Wall 3 and Wall 4 between sill and lintel bands (mid height), with additional inclined cracks on panel (between sill and lintel band) at the wall corners. Toe crushing at base of buttress was observed during rocking of Wall 1. Few slight cracks also appeared in panel over Wall 3 between eave and lintel bands.

Increase in frequency up to 6 Hz and under imposed displacement up to 3 mm, the buttress on wall 1 was observed with significant rocking at lintel level. Under further increase in table displacement up to 6mm, horizontal cracks in panel over Wall 3 increased in number and the existing cracks further widened. Sliding out of brick units from Wall 3 was observed over wall panel between lintel and eave bands and lintel and sill bands, with a brick unit fall from panel between lintel and eave band. Severe out-of-plane rocking of buttress was observed on Wall 1, a wedge like portion from buttress was about to separate right below the lintel band. Diagonal cracks (passing through mortar joints) were also observed on Wall 1 between buttress and door opening, over wall panel between sill and lintel bands. Frequency of excitation was increased but no significant damage was observed except localized vibrations of units, with a fall of a brick unit under excitation of 8 Hz frequency.

After high frequency excitation, the model was again subjected to excitation with frequency of 6 Hz and imposed displacement of 6 mm, masonry splitting was observed at the toe of buttress on out-of-plane rocking Wall 1. Buttress on Wall 1, right below the lintel level, detached with wedge like masonry. Sliding out of further brick units was observed on Wall 3 and Wall 4.

Excitation with 4 Hz frequency was also repeated. For this frequency and imposed displacement of 12 mm, the model was observed with toe crushing of buttress of wall 1 and also separation of masonry wedge from buttress right below the lintel band. Damage to corner of walls between Wall 1 and Wall 4 was also observed right below the lintel band. Under further increase in imposed displacement up to 15 mm, out of plane failure of bricks was observed at corner of Wall 1 and Wall 4 just below lintel band. However, this didn't jeopardize the stability of structure, as the vertical elements were still able to provide vertical support to the structures. Out-of-plane failure of and fall of significant number of brick units from panel of Wall 1 between sill and lintel band was observed. Appendix G3 reports all the test runs with respective observed damages while Appendix H3 presents photographs of observed damages under significant runs.

This model was then cosmetically repaired for retesting. The model was repaired by replacing the damaged wall with new CSEB units in cement stabilized mud masonry. Few bricks in walls cracked/broken were also replaced with new units and the buttresses were removed. The model was tested under similar protocol of that virgin model. The repaired model behaved almost similar to the virgin model; initially cracking and spalling of mortar was observed that was followed by masonry sliding at the bed joint. Under resonance frequency, the model was observed with significant damages in walls; falling units from walls and masonry crushing at the model corner were observed. The model was still able to resist peak base acceleration of 0.80g. Detailed damage observations of the repaired model are reported in G3-R.

1/3rd Scale Model

Under EQ1 shaking, the design level earthquake excitation, during the initial “self-check” of the shake table, the model was subjected to strong seismic excitation by the system than intended. This resulted in significant damage to the model. The model under this run was observed with significant horizontal cracks in in-plane Wall 3 and Wall 4. Horizontal sliding of lintel and eave bands was also observed. Toe crushing of buttresses on wall 1 and wall 3 was also observed. As planned, the model was subjected to design level earthquake record (EQ1), with multiple intensities varying from 5% to 100% following the self-check of the table. However, no further notable damage was observed.

The model was then subjected to rare earthquake ground motion (EQ2) i.e. simulated through scaling design level earthquake to PGA of 1.0g. The model was first subjected to “self-check” before starting EQ2 shaking, which was followed by runs with multiple intensities varying from 60% to 100%. The existing cracks in walls further aggravated under 70% of EQ2. Also, falling of bricks from W3 just above sill level was observed due to shear cracking. Toe crushing of Wall 3 at the corner i.e. at junction of Wall 3 and Wall 2, was observed. Under 100% of EQ2, further falling of brick units from buttress of Wall 3 was observed at the horizontal shear cracks. Corner wedge separation at toe of Wall 3 and Wall 4 observed. In-plane cracks both to Wall 3 and Wall 4 were aggravated, however, the extent of damage was high on wall having no buttress. Sliding out of brick units was observed over in-plane Wall 4 between sill and lintel band, right above the stitch location. Appendix I3 reports all the test runs with respective observed damages while Appendix J3 present photographs of observed damages under significant runs. This model was not tested for KIRT-EW to save it for post repair testing.

This model was also repaired to investigate its performance under the testing protocol similar to that of virgin model. First the damaged part of masonry was replaced and the model was then plastered to conceal the previous cracks. The repaired model under EQ1 and EQ 2 behaved similar to the virgin model; existing cracks reappeared in the model and sliding was observed at lintel bands. The in-plane walls suffered diagonal cracking (cracks passing through mortar joints) in the masonry panel between lintel and sill levels. The out of plane walls were observed with significant rocking. Masonry walls crushing at in-plane walls corners was observed. Falling of few units was also observed. However, the model still possessed capacity to resist shaking. Detailed damage observations of the repaired model are reported in I3-R.

This model was rotated and tested in the longitudinal direction under the same testing protocols. The model in this direction was observed with significant rocking of in-plane piers on long walls. Since, the model was already significantly softened under the transverse excitations, the out of plane sliding and fall of brick units from out of plane walls were observed under intense shaking. The model was found at the incipient collapse state. It is worth mentioning that the model under longitudinal excitation was severely damaged already under multiple phases excitations in transverse direction. Detailed damage observations of the repaired model in longitudinal direction are reported in I3-RL.

5.3.4 Type Design 4

General

Both the 2/3rd and 1/3rd scale model buildings behaved very similar under subjected input base excitations. However, in general the 2/3rd scale model suffered more damage than the 1/3rd scale model, although the patterns were similar. Under low and moderate shaking, the model buildings didn’t show any significant/visible damages in structural or non-structural components other than a few cracks. Under moderate to strong shaking, the models were observed with few plaster spalling particularly at the base levels (between plinth and sill level) and at eave level. Unlike models of Type Design 1, models of Type Design-4 showed significant horizontal sliding of timber bands at sill, lintel and eave levels with prominent sliding at eave level and sill levels. One of the truss connection right above the buttress was detached and few purlins were also detached. Overall, the model was observed with significant rocking of the face-loaded walls (front wall W1 and rear wall W2).

2/3rd Scale Model

Under base excitation of 4 Hz frequency and imposed base displacement of 3 mm, the model was observed with intense out-of-plane rocking of walls (W1, W2), prominently at the lintel band (rocking of masonry panel between lintel and eave level). Under further large displacement of 15 mm for the said excitation (i.e. at 4 Hz), a few of the small stones fell off the W1 (front wall) and W4 (side wall) with a few more dislocated but did not fall. Stone falling was observed particularly from the buttresses at the lintel level (right below the lintel band). Unlike models of Type Design - 1, Type Design – 4 model was observed with multiple rocking of Wall 1 and Wall 2 (face loaded wall) at plinth, sill and lintel levels. This showed face loaded walls of Type Design - 4 was relatively more flexible than Type Design - 1. This was possibly due to the timber bands, which are more flexible than the reinforced concrete bands and effect of using wires for containment instead WWM (welded wire mesh). However, despite all the intense shaking, the model and its components did not trigger any unstable mode of failure or loss of masonry units. Appendix G4, provided with the excel sheet, shows each run with the observed significant damages. Appendix H4 records photographic images of the damage suffered by the model.

1/3rd Scale Model

Under EQ1 shaking, the design level earthquake excitation, during the initial "self- check" of the shake table, the model was subjected to strong seismic excitation by the system than intended. This resulted in significant damage to the model. The model under this run experienced horizontal sliding of timber bands, clear horizontal sliding at sill and lintel levels on all of the walls. As planned, the model was subjected to design level earthquake record

(EQ1), with multiple intensities varying from 5% to 100% following the self-check of the table.

The model was then subjected to rare earthquake ground motion (EQ2) i.e. simulated through scaling design level earthquake to PGA of 1.0g. The model was first subjected to "self-check" before starting EQ2 shaking. Although not intended, under this run also the model was subjected to 1.06g shaking due to the shake table malfunction. The model experienced significant out-of-plane rocking of long walls, following spalling of plaster from long walls. Also, truss connection has shown significant horizontal sliding and rocking that forced connections failure.

The model was then subjected to Gorkha earthquake recorded at Kirtipur on rock site (KIRT_EW). Under this run, the modal experienced very large deformation of long walls due to out-of-plane bending and rocking because of the long period contents of the record. However, despite large displacement and horizontal sliding of the bands, the model remained intact without triggering any unstable mode of failure. The model suffered plaster spalling.

To check sensitivity of survival of model to the containment mesh, the 50% and 100% of containment mesh wires were removed (each alternative wire was removed) from both in-plane and out-of-plane walls and the model was subjected to EQ2 and KIRT-EW. The walls with 50% containment behaved very similar to the case with 100% containment mesh. However, a few stone falls were observed at the sill and lintel level bands on long walls (walls W1 and W2). In case of walls where 100% containment mesh had been removed, significant sliding of stones and wide cracks in the walls were observed. Appendix I4 provides testing sequence along with observed significant damages with these runs. Appendix J4 shows photos of the damage suffered by the model.

CHAPTER 6: RESULTS AND DISCUSSIONS

6.1 Introduction

This section discusses the experimental recorded data analysis for calculation of various elastic and inelastic seismic response properties, listed as follows:

- Fundamental vibration period
- Structural damping
- Acceleration amplification
- Force-displacement capacity curves
- Ductility and response modification factors
- Damage states and performance Levels

The above listed properties for each Type Design are further elaborated in the following sections.

6.2 Fundamental Periods

Free vibration tests data were analyzed for estimation of fundamental frequency of the models. The uncracked fundamental period of model was estimated using the data from free vibration F1 test run. The time history response of acceleration recorded at the eave level was obtained and analyzed in SeismoSignal for base line correction and filtering. Fourier amplitude of acceleration was correlated with the frequency to obtain the power spectral density (PSD).

Figure 57 shows the PSD obtained for 2/3rd scale model for out-of-plane responding wall while Figure 58 shows PSD obtained for in-plane walls of Type Design 1. The minimum frequency at the peak response was obtained as the resonance frequency, which is 8.20 Hz (0.122 sec) for out-of-plane wall and 8.45 Hz (0.118 sec) for in-plane wall. This corresponds to prototype fundamental vibration period, calculated as $\sqrt{(3/2)} \times 0.122 = 0.15$ sec for out-of-plane and √(3/2) x 0.182 = 0.145 sec for in-plane response of structure. For both in-plane and out-of-plane response, and for all Type Designs, maximum frequency at peak response was obtained as the resonance frequency that basically corresponds to initial uncracked frequency.

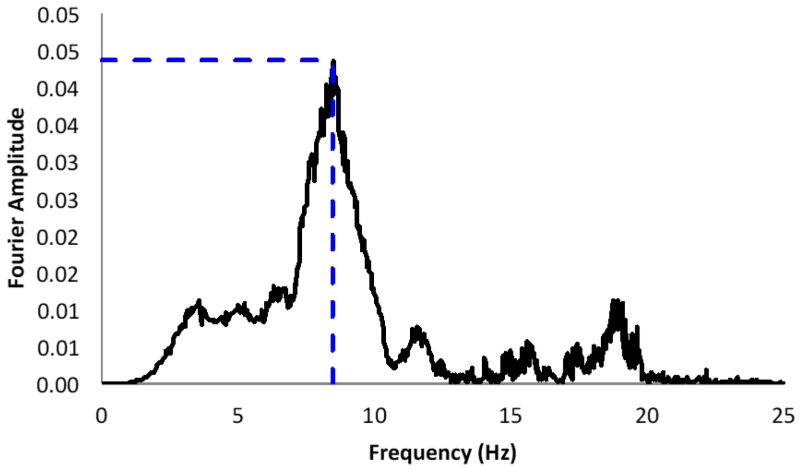


Figure 57: PSD developed for free vibration acceleration response of 2/3rd scale model for out-of-plane response- Type Design 1

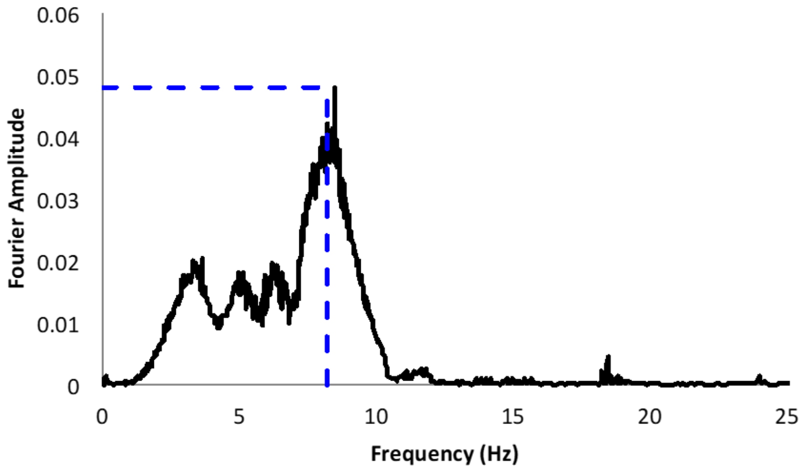


Figure 58: PSD developed for free vibration acceleration response of 2/3rd scale model for in-plane response- Type Design 1

Figure 59 shows the PSD obtained for 2/3rd scale model for out-of-plane responding wall while Figure 60 shows PSD obtained for in-plane walls of Type Design 2. The minimum frequency at the peak response was obtained as the resonance frequency, which is 5.50 Hz (0.18 sec) for out-of-plane wall and 10.74 Hz (0.09 sec) for in-plane wall. This corresponds to prototype fundamental vibration period, calculated as √(3/2) x 0.18 = 0.22 sec for out-of-plane and √(3/2) x 0.09 = 0.11 sec for in-plane response of structure. For both in-plane and out-of-plane response, maximum frequency at peak response was obtained as the resonance frequency that basically corresponds to initial uncracked frequency.

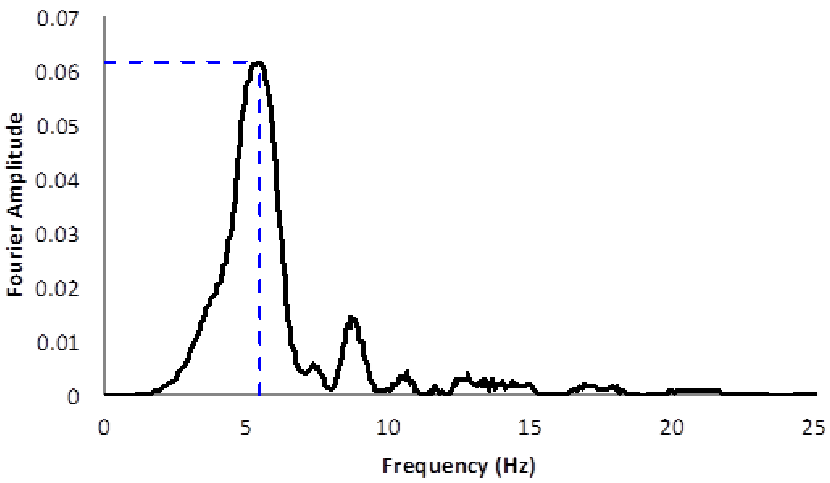


Figure 59: PSD developed for free vibration acceleration response of 2/3rd scale model for out-of-plane response- Type Design 2

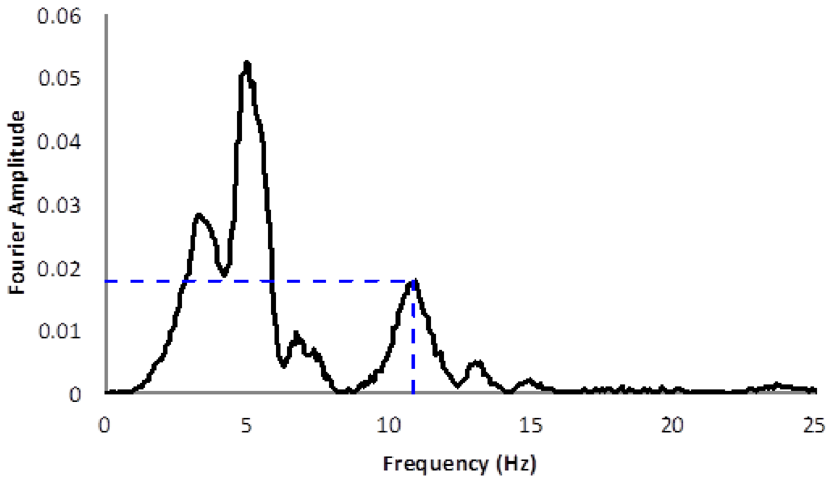


Figure 60: PSD developed for free vibration acceleration response of 2/3rd scale model for in-plane response- Type Design 2

Figure 61 shows the PSD obtained for 2/3rd scale model for out-of-plane responding wall while Figure 62 shows PSD obtained for in-plane walls of Type Design 3. The minimum frequency at the peak response was obtained as the resonance frequency, which is 9.40 Hz (0.11 sec) for out-of-plane wall and 9.40 Hz (0.11 sec) for in-plane wall. This corresponds to prototype fundamental vibration period, calculated as √(3/2) x 0.11 = 0.13 sec for out-of-plane and √(3/2) x 0.11 = 0.13 sec for in-plane response of structure. For wall response, maximum frequency at peak response was obtained as the resonance frequency that basically corresponds to initial uncracked frequency.

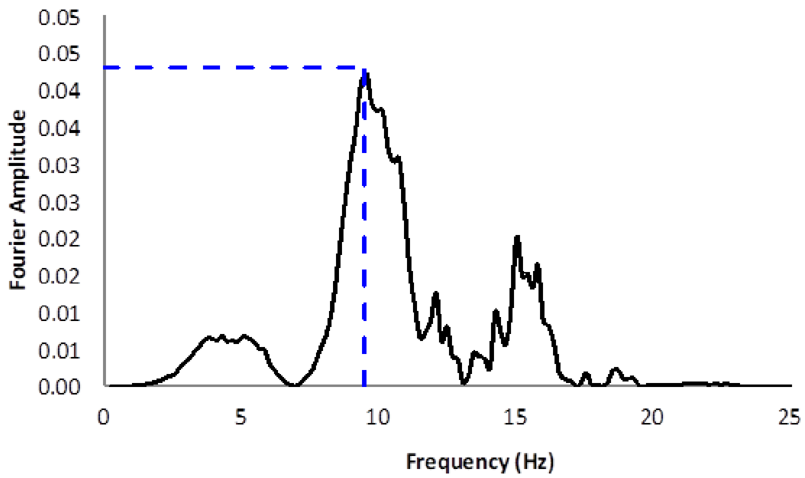


Figure 61: PSD developed for free vibration acceleration response of 2/3rd scale model for out-of-plane response- Type Design 3

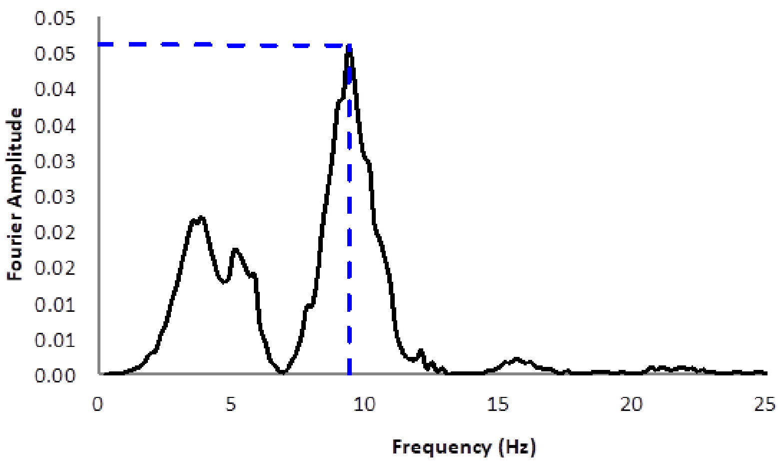


Figure 62: PSD developed for free vibration acceleration response of 2/3rd scale model for in-plane response-Type Design 3

Figure 63 shows the PSD obtained for 2/3rd scale model for out-of-plane responding wall of Type Design 4. The minimum frequency at the peak response was obtained as the resonance frequency, which is 3.96 Hz (0.25 sec) for $2/3^{rd.}$ Model. This corresponds to prototype fundamental vibration period, calculated as √ (3/2) x 0.25 = 0.31 sec. Similarly, Fig Figure 64 shows the PSD obtained for $2/3^{rd}$ model for in-plane responding walls of Type Design 4. The maximum frequency at the peak response was obtained as the resonance frequency (this basically corresponds to initial uncracked frequency), which is 8.40 Hz (0.12 sec) for $2/3^{rd}$ model. This corresponds to prototype fundamental vibration period of 0.15 sec.

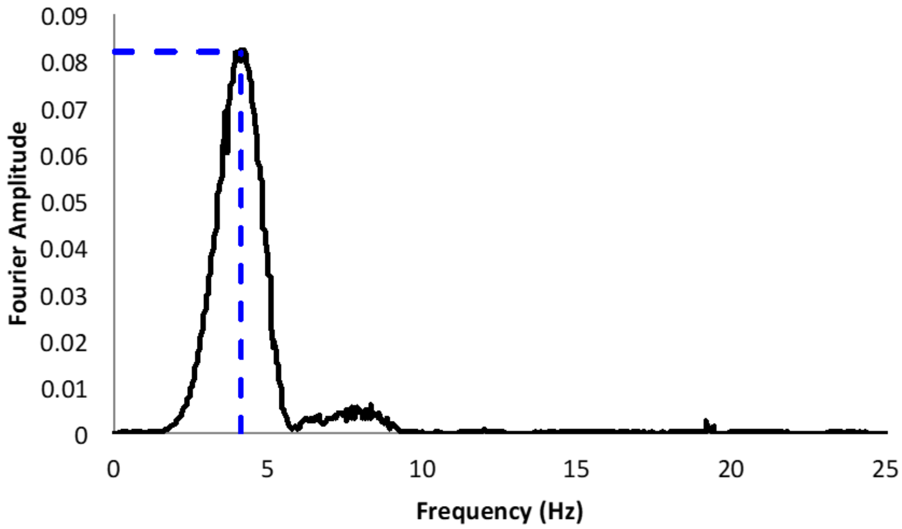


Figure 63: PSD developed for free vibration acceleration response of $2/3^{rd}$ scale model for out-of-plane response – Type Design 4

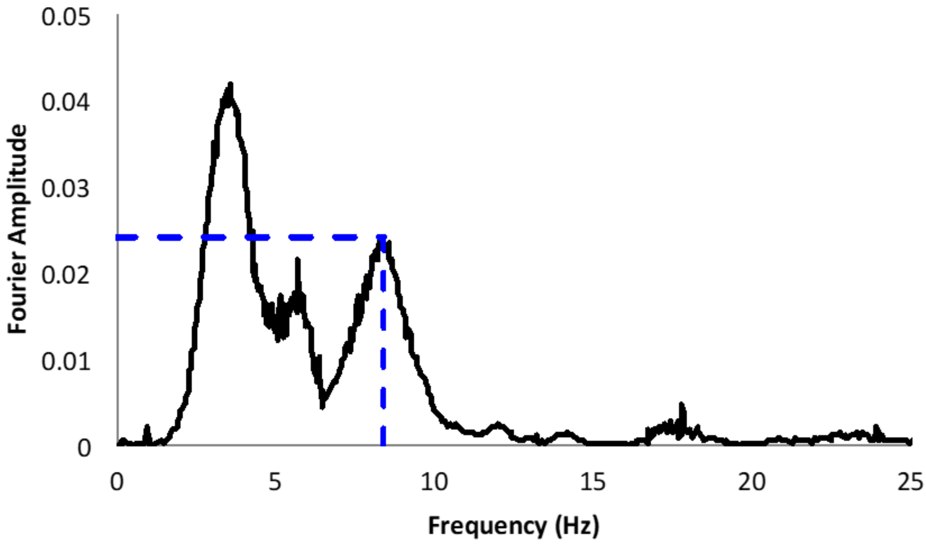


Figure 64: PSD developed for free vibration acceleration response of $2/3^{rd}$ scale model for in-plane response – Type Design 4

Comparison of Fundamental Time Period of Type Designs

Table 21 reports the fundamental period for prototype of all Type Designs. Slight variation was observed in the time period of models for in-plane response, whereas the variation in the time period seemed considerable for out-of-plane responding walls, which was expected. Models with RC bands (Type Design 1 and 3) that ensured in-plane integrity of the structural walls observed with similar time period for both in-plane and out-of-plane responses, indicating coupled in-plane and out-of-plane response of model. This further indicates the global in-plane mechanism of the models.

Models with flexible bands like gabions (Type Design 2) and timber truss (Type Design 4) exhibited higher time period for out-of-plane response. The in-plane and out-of-plane periods of these models were well apart, indicating de-coupled in-plane and out-of-plane response of the models. Free vibration tests conducted after actual test run indicated that the time period of all models elongated with the onset of damage during actual test runs. Fundamental time period up to 0.40 sec was observed for damaged models.

Table 21: Fundamental time period for prototype of all Type Designs (based on virgin models)

Type Design	Time Period (sec)	
	In-Plane	Out-of-Plane
Type Design 1	0.15	0.15
Type Design 2	0.11	0.22
Type Design 3	0.13	0.13
Type Design 4	0.15	0.31

6.3 Damping

The decay function for the time history of the response acceleration as proposed by Chopra (2003) is used to calculate the model damping:

$$z = \frac{1}{2n\rho} Ln\left(\frac{A_1}{A_n}\right)$$

where ζ represents elastic damping coefficient; A_1 represents the peak amplitude of response displacement at reference point 1; A_n represents the peak amplitude of response displacement at reference point after n cycles; and n represents the number of cycles between the peaks.

The models' damping was calculated from the free vibration tests of the model, carried out by means of table impulse loading. The structure displacement response at the top was considered and analyzed for calculating the decay in the displacement history. The damping was calculated from the logarithmic decay of the last two cycles. Table 22 reports the final maximum and final average structural damping ratio for all the Type Designs.

An initial structural damping up to 10% was observed for all the models, which has also been confirmed by similar tests conducted by others on similar building types with weak mortar (Benedetti et al, 1998).

The experimental investigation has shown that all the models possessed significantly higher initial and final structural damping as compared to other structural types such as steel and reinforced concrete structures.

Table 22: Viscous damping of all Type Designs (based on virgin models)

Type Design	**Final Structural Damping Ration (%)**	
	Max.	**Avg.**
Type Design 1	31	25
Type Design 2	32	21
Type Design 3	33	20
Type Design 4	32	25

6.4 Amplification

The model amplification was calculated for face loaded (i.e. long walls) walls when the model was shaking in the transverse direction. It was calculated by dividing the structural peak response acceleration (at eave level at the top of the buttress on the long wall) over the peak input acceleration at the base of the model (base of buttress on long wall).

$$Amp = \left(\frac{\max A_{eave}}{\max A_{base}} \right)$$

where Amp represents the amplification factor; max A_{eave} represents the peak acceleration observed at the eave level, at mid-span of long wall (i.e. at the top of the buttress on the long wall); max A_{base} represents the peak acceleration observed at the base of the model (i.e. at the base of the buttress on the long wall). Table 23 reports the maximum and average amplification factors estimated for all Type Designs.

Table 23: Acceleration amplification factor of all Type Designs (virgin models)

Type Design	**2/3rd Models**		**1/3rd Models**	
	Max.	**Avg.**	**Max.**	**Avg.**
Type Design 1	3.96	2.06	2.91	1.74
Type Design 2	2.32	1.80	3.47	2.67
Type Design 3	3.26	2.08	3.13	1.94
Type Design 4	3.72	2.72	3.07	2.33

6.5 Capacity Curves

Lateral force-deformation capacity curves for both in-plane and out-of-plane response of test models were developed. Both the in-plane and out-of-plane response modes of structure are considered as uncoupled modes of vibration for calculating in-plane and out-of-plane capacity curves. This will facilitate mode specific design and assessment of similar structures.

For in-plane capacity curve, the in-plane walls' peak relative displacement response observed at the eave level was normalized over the in-plane wall height to calculate in-plane walls' drift.

The in-plane capacity of test model was presented in terms of base shear coefficient (BSC), which is calculated using the procedure described in Ali et al. (2013). This involved transforming model observed peak acceleration on in-plane walls (average of the two in-plane walls) at the eave level to prototype using the actual applicable scale factors for model to prototype conversion (Tomazevic, 2000). The in-plane walls' response acceleration was multiplied by the structural masses including self-weight of roof (timber trusses and purlins and GI Sheet) and loadbearing walls (considered as 50% of the total mass of walls).

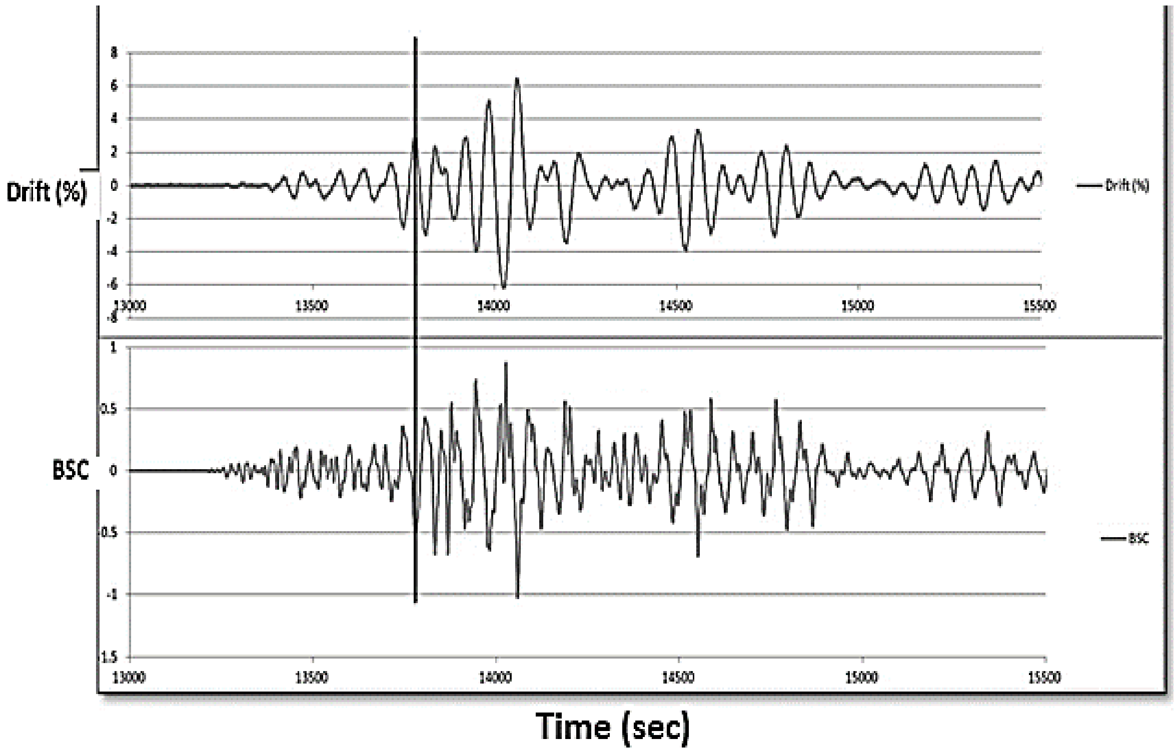


Figure 65: Drifts and corresponding base shear coefficient

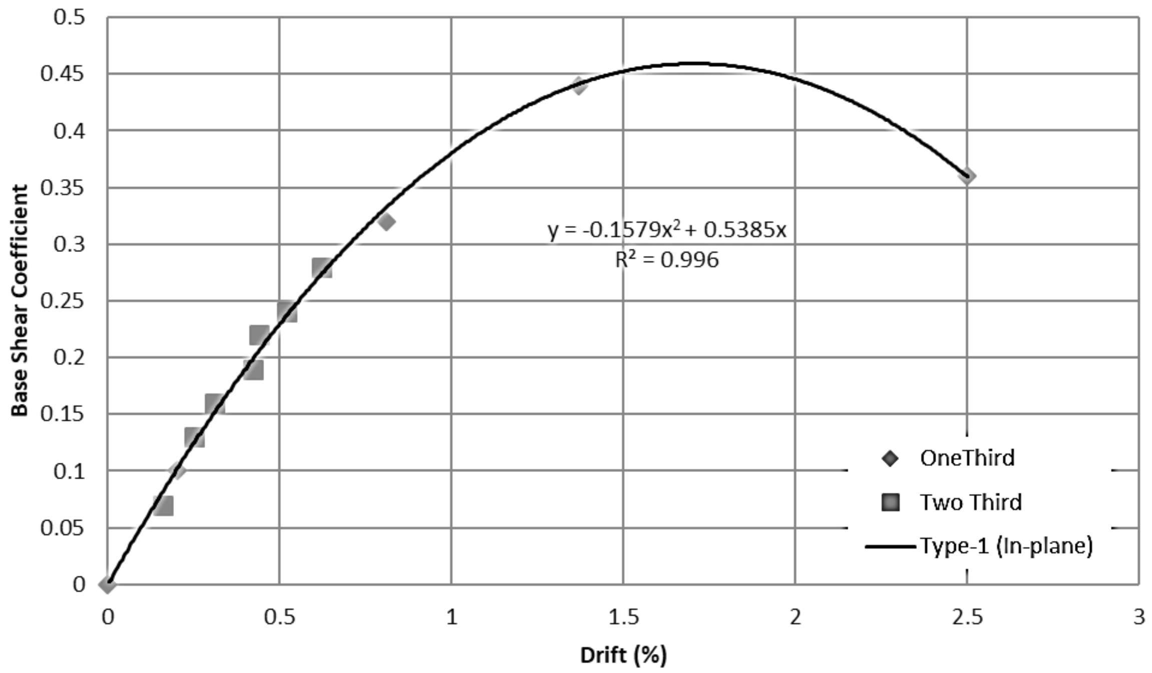


Figure 66: Adopted Lateral Force Deformation Capacity Curves- Combined (2/3rd and 1/3rd)- Type Design 1

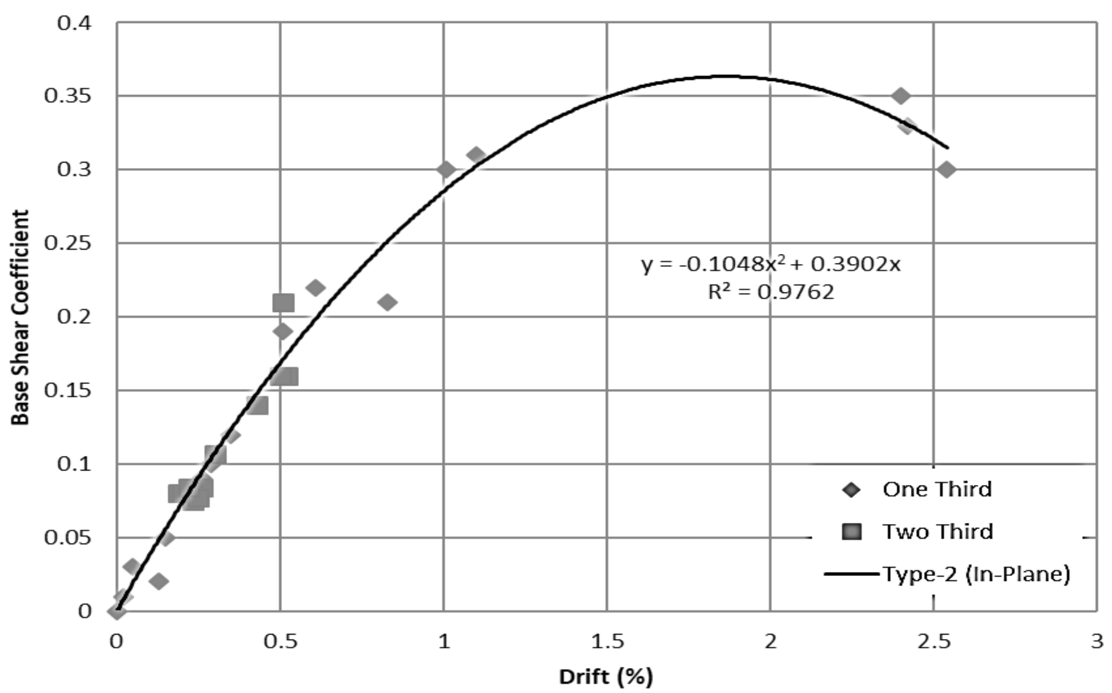


Figure 67: Adopted Lateral Force Deformation Capacity Curves- Combined (2/3rd and 1/3rd)- Type Design 2

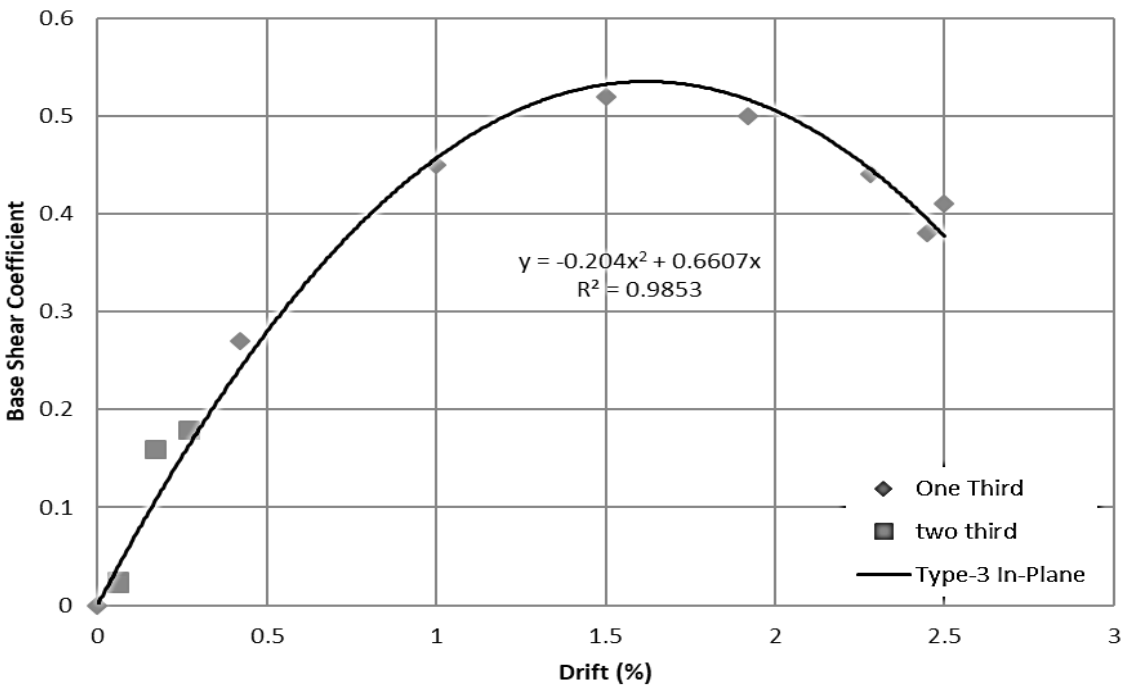


Figure 68: Adopted Lateral Force Deformation Capacity Curves- Combined (2/3rd and 1/3rd)- Type Design 3

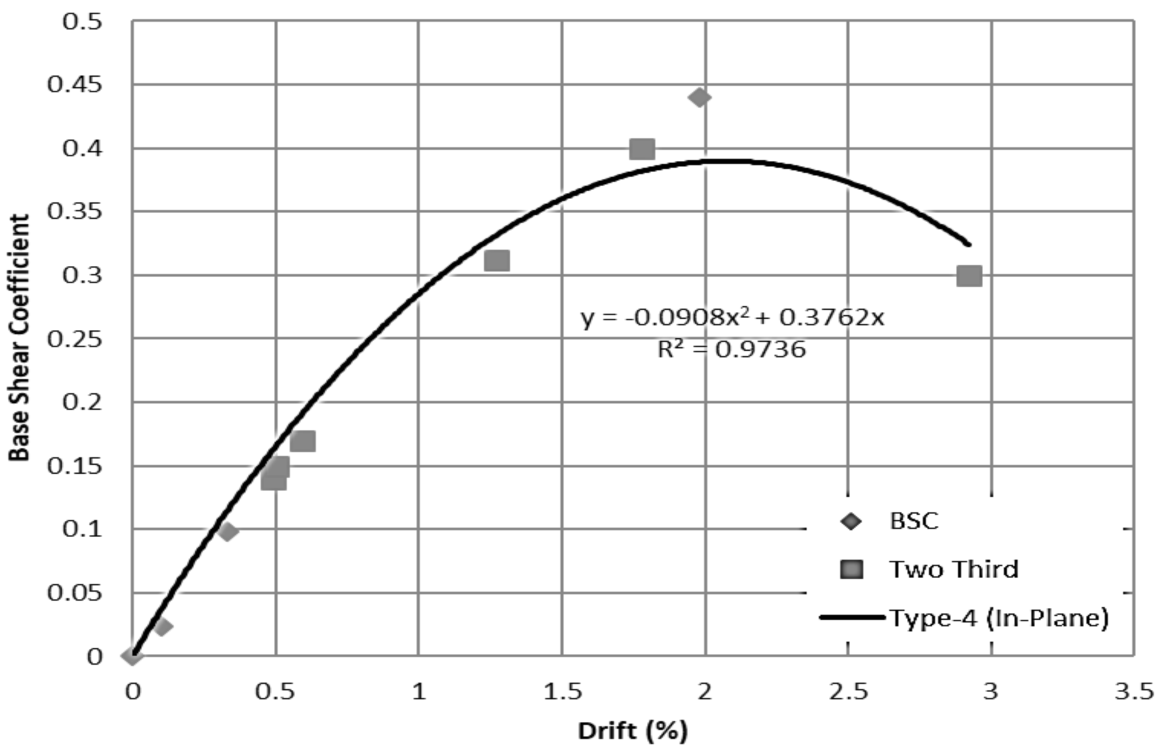


Figure 69: Adopted Lateral Force Deformation Capacity Curves- Combined (2/3rd and 1/3rd)- Type Design 4

In-plane drifts and base shear coefficients for both one third and two third scaled models were calculated and plotted individually for each run, as shown in Figure 65.

Peaks from both the plots were obtained for each run and plotted against each other. Since the plotted data was too scattered, standard procedure for selecting points was not followed. After discussions, the procedure followed is; taking into account stiffness of the model, lines were marked in the plotted graph to remove outliers from the plot. After removing outliers, final plots are shown in Figure 66 to Figure 69. Although the models were able to deform beyond 2.5% drift remaining stable, generally 2.5% adopted was considering limited data available after 2.5% drift.

6.6 Ductility and Response Modification Factors

In the present research the seismic response modification factor R of structural models is calculated by the procedure used by Ali et al (2013). Generally, R factor for a structure can be calculated knowing the inelastic lateral force-deformation behavior of the structure.

$$R = \frac{V_e}{V_s} = \frac{V_e}{V_y} * \frac{V_y}{V_s} = R_m * R_s$$

Where, Ve represents the elastic force the structure will experience, if responded elastically under earthquake demand; Vy represents the idealized yield strength of the structure; Vs represents the design base shear force; Rμ represents the ‘ductility factor’, i.e. structure ductility dependent factor, R_S represents the ‘overstrength factor’, i.e. structure overstrength dependent factor. The overstrength factor R_S is calculated directly from the lateral force-deformation capacity curve of the structure (i.e. dividing the idealized yield strength over the structure design strength), however, the ductility factor Rμ is related to the structural ductility (Newmark and Hall, 1982, Tomazevic, 1999) as given:

Short Period	$T < 0.20$ sec.	$R_m = 1.0$	Structure Vibration Period:
Intermediate Period	0.2 sec. $< T <$ 0.5 sec.	$R_m = \sqrt{2m-1}$	
Long Period	$T >$ 0.5 sec.	$R_m = n$	$T = 2p\sqrt{\frac{m}{k_y}}$

Where, T is the yield vibration period of idealized single degree of freedom system. Using the classical formulae of time period i.e. $T_y = 2\pi(m/k_y)^{0.5}$, Ty (sec) = 0.51, 0.60, 0.50 and 0.62 were calculated for Type Design 1, 2, 3 and 4, respectively. It is worth mentioning that the yield period is based on the elasto-plastic idealization of system and thus depends on the yield stiffness of the system, which is usually larger than the initial stiffness. Therefore, the yield period is always greater than the initial period or period obtained through low amplitude free vibration tests. This suggests using the ductility and R relationship recommended for long period structures in order to estimate R factor for all Type Designs. This has been supported also by the observed dynamic seismic response of the models, exhibiting flexible behavior; deforming to very large lateral drift and exhibiting multiple rocking and sliding behaviors.

Bi-linearized Capacity Curves for Prototype Structure

R factor calculated in this research is model specific and based on the combined data of models for global response. For this purpose, the force-deformation capacity curve data obtained from both the 2/3rd and 1/3rd models were combined, and a single capacity curve was developed for prototype structure.

For calculation of structural global ductility and yield force, the structure force-deformation capacity curve was bi-linearized as an elasto-plastic curve (Figure 70 to Figure 73), based on the energy-balance criterion (Magenes and Calvi, 1997). The structure's global ductility μ was obtained by dividing the ultimate displacement capacity over the idealized yield displacement capacity of structure model. The ultimate displacement was limited to close to 2.5% drift, despite the models were stable at much higher drifts. The results indicate that R factors calculated for tested structures are marginally higher than the IS: 1893:2016 specified R factor. Response modification factors are reported in Table 24, which are applicable to both in-plane and out-of-plane response. R factor for all models may be approximated as 2.50 for the design and assessment of structures of similar constructions.

Table 24: Response Modification Factors-R

Type Design	Yield Drift	Ultimate Drift	Ductility	Rμ	Rs	R
Type Design -1 Stone Masonry with RC Bands	0.95	2.47	2.60	2.60	1	2.60
Type Design -2 Stone Masonry with Gabion Bands	1.03	2.69	2.61	2.61	1	2.61
Type Design -3 CSEB	0.90	2.34	2.60	2.60	1	2.60
Type Design -4 Stone Masonry with Timber Bands	1.17	3.00	2.58	2.58	1	2.58

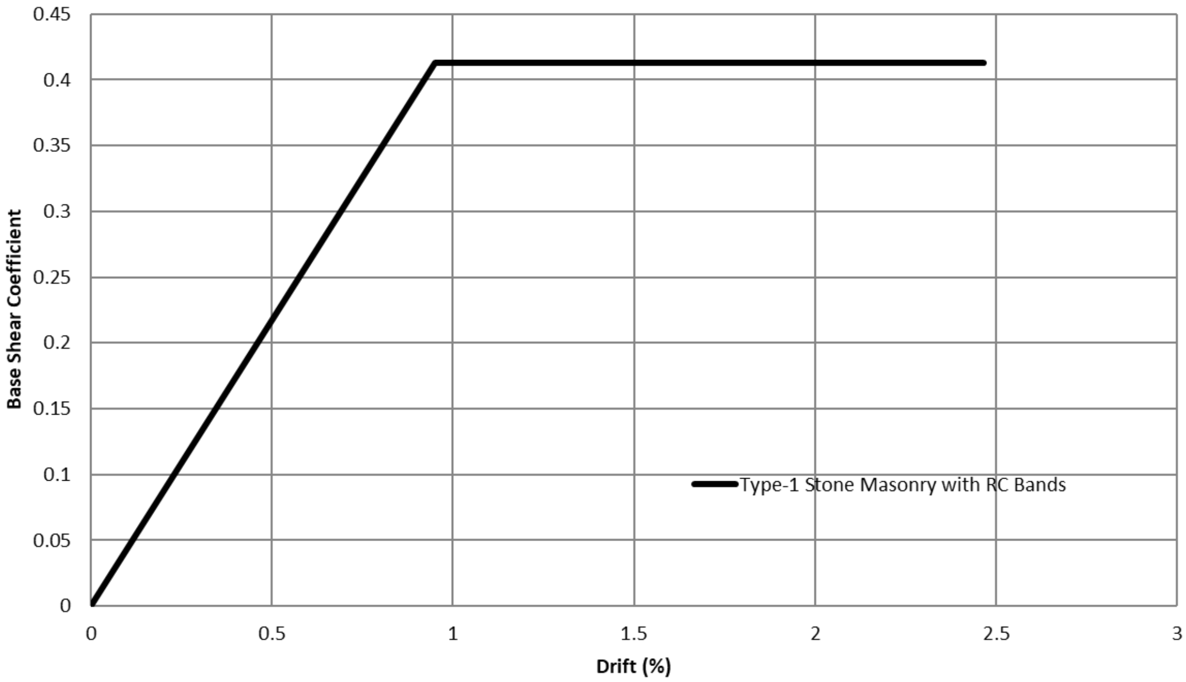


Figure 70: Bi-Linearized Lateral Force Deformation Capacity Curve- Type Design 1

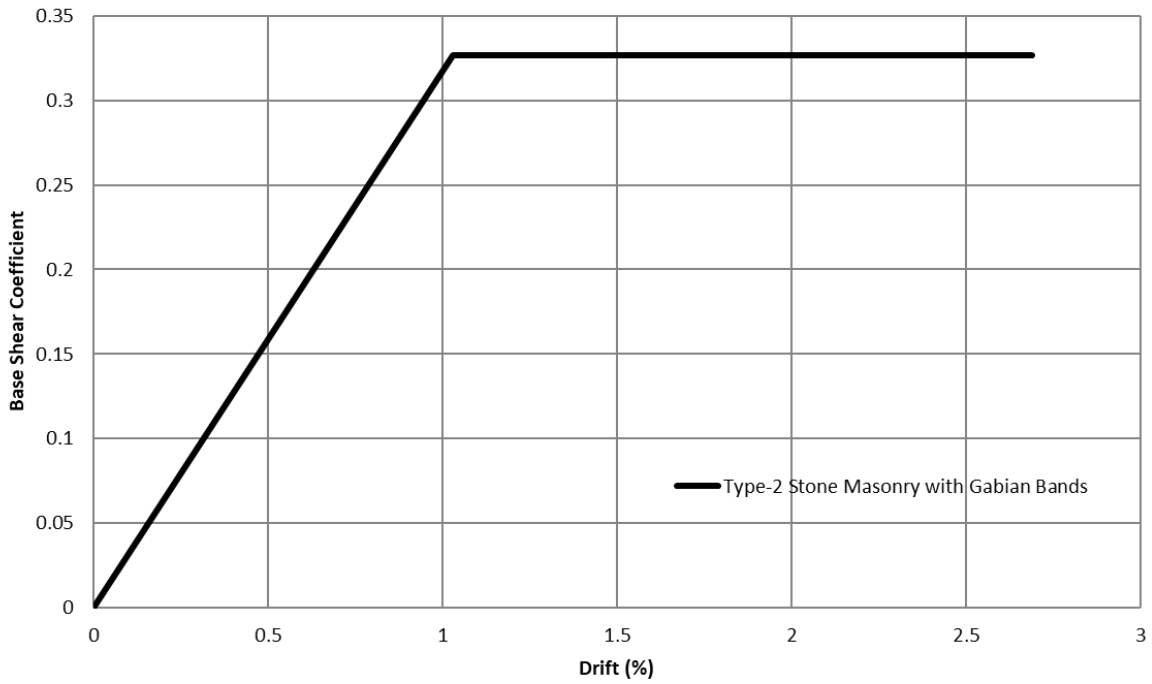


Figure 71: Bi-Linearized Lateral Force Deformation Capacity Curve- Type Design 2

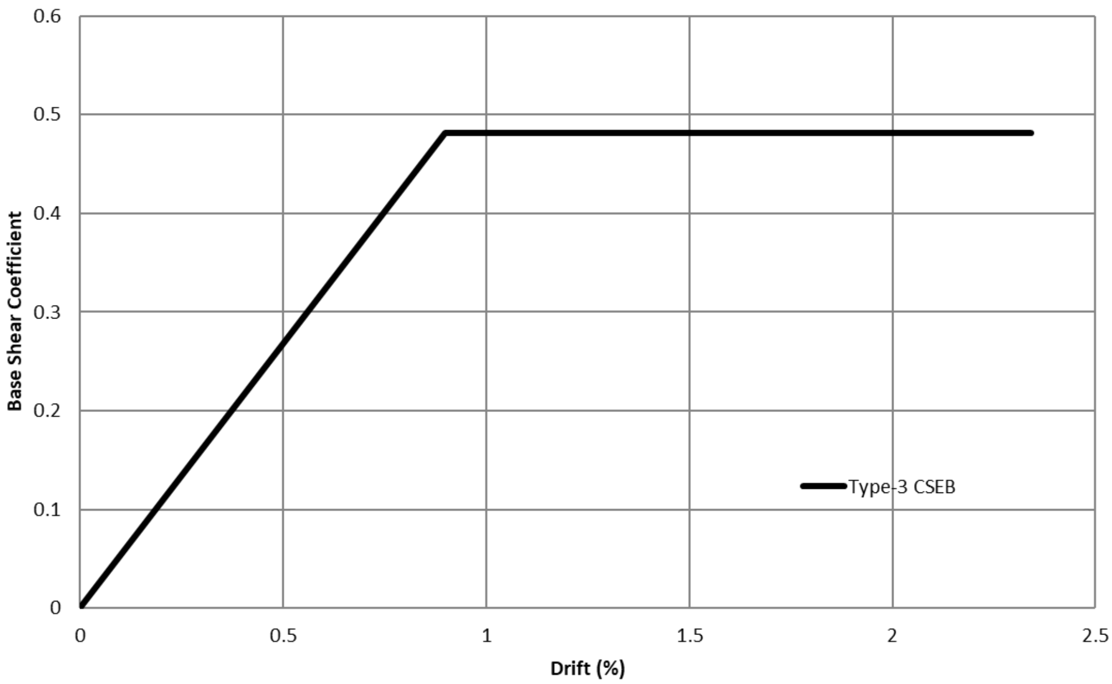


Figure 72: Bi-Linearized Lateral Force Deformation Capacity Curve- Type Design 3

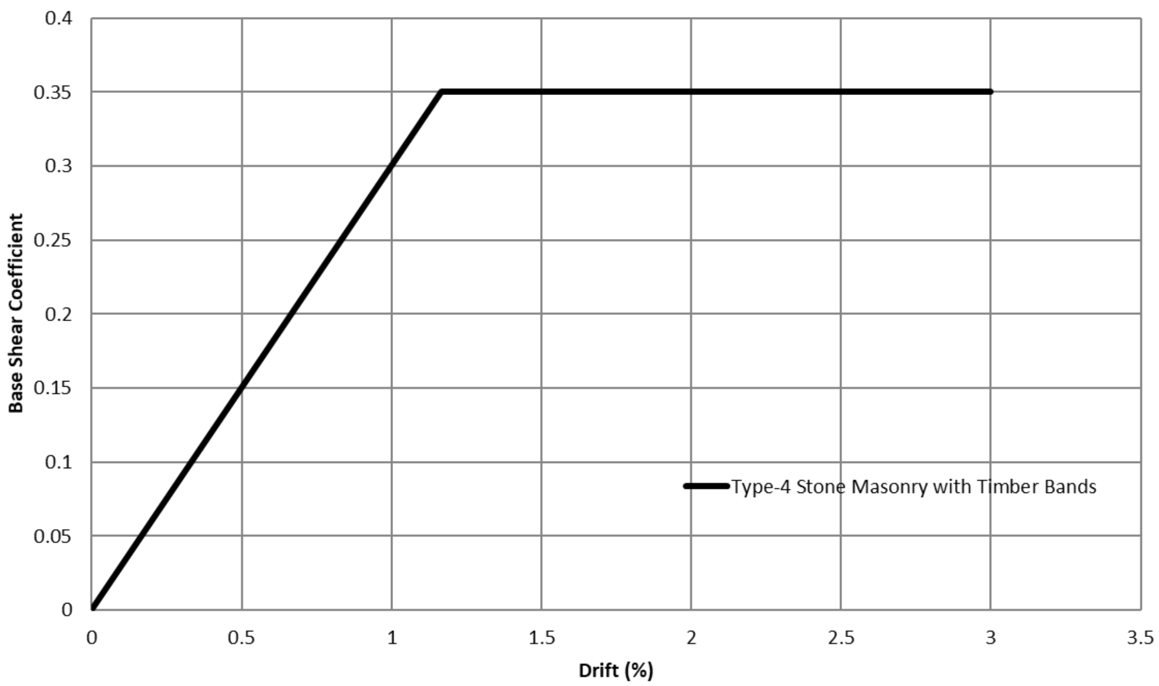


Figure 73: Bi-Linearized Lateral Force Deformation Capacity Curve- Type Design 4

6.7 Damage states and performance levels

Attempts were made to define seismic performance levels were determined as Immediate Occupancy Level (IO), Life Safety Level (LS) and Collapse Prevention Level (CP), in accordance with the guidelines document, FEMA 273 (1997) for seismic rehabilitation of buildings. The drift corresponding to 20% drop in the base shear force of structure was assumed as the CP limit state. The LS limit state drift has been taken as 75% of the CP level drift. The IO level has been taken as 70% of the idealized yield drift of the structure. The corresponding base shear coefficients for each drift limits were calculated from the equation of back bone curve. (Refer Table 25).

In order to examine the usability of all four Type Design in various seismic zones of Indian Standard IS: 1893-2016, performance-based assessment of structures was carried out. The 5% damped demand base shear coefficient (A_h) for each zone was compared with the experimental base shear coefficient (BSC_e) in order to evaluate the seismic performance of structures in each seismic zone. The BSCe has also been compared with conservatively adopted 8%

damped BSC, although the tests have shown initial damping up to 10%. The BSC_e is taken equal to the life safety BSC. Seismic performance of each Type Design in various zones is shown in Table 26.

Table 25: Performance Levels of all Type Designs

	Parameters	Immediate Occupancy	Life Safety	Collapse Prevention
Type Design -1	**Drift (%)**	0.67	1.85	2.47
	BSC	0.29	0.46	0.37
Type Design -2	**Drift (%)**	0.72	2.02	2.69
	BSC	0.23	0.36	0.29
Type Design -3	**Drift (%)**	0.63	1.76	2.34
	BSC	0.34	0.53	0.43
Type Design -4	**Drift (%)**	0.82	2.25	3.00
	BSC	0.25	0.39	0.31

Table 26: Seismic performance in various seismic zones (Indian IS:1893-2016)

Type Design	Zone	Level of Seismic Hazard	Zone Factor – Z	Demand BSC** (5% damping) Ah = (Z x I x Sa)/ (2 x R x g) *L. F	Demand BSC** (8% damping)	BSCe	Seismic Performance
Type Design - 1	II	Low	0.1	0.11	0.09	0.46	**OK**
	III	Moderate	0.16	0.18	0.14		**OK**
	IV	Severe	0.24	0.27	0.22		**OK**
	V	Very Severe	0.36	0.41	0.33		**OK**
Type Design - 2	II	Low	0.1	0.11	0.09	0.36	**OK**
	III	Moderate	0.16	0.18	0.14		**OK**
	IV	Severe	0.24	0.27	0.22		**OK**
	V	Very Severe	0.36	0.41	0.33		**OK**
Type Design - 3	II	Low	0.1	0.11	0.09	0.53	**OK**
	III	Moderate	0.16	0.18	0.14		**OK**
	IV	Severe	0.24	0.27	0.22		**OK**
	V	Very Severe	0.36	0.41	0.33		**OK**
Type Design - 4	II	Low	0.1	0.11	0.09	0.39	**OK**
	III	Moderate	0.16	0.18	0.14		**OK**
	IV	Severe	0.24	0.27	0.22		**OK**
	V	Very Severe	0.36	0.41	0.33		**OK**

** Based on calculated R-factor

CHAPTER 7: CONCLUSIONS

7.1 Global Behavior

The 2/3rd and 1/3rd models of Type Design 1, 2, 3 and 4, were subjected to sinusoidal and seismic excitations with moderate to high levels of peak ground acceleration, ranging up to 1.0g. All the models survived without partial or total collapse of walls triggering any unstable mode of failures, other than fall of few bricks and partial collapse of a buttress in case of Type Design 3, indicating the overall satisfactory structural performance of the models. The reason for avoiding collapse in case of stone masonry models was the effectiveness of horizontal bands coupled with surface containment. The good behavior of CSEB model was due to the provision of horizontal bands and vertical rebars at wall corners and jambs.

7.2 Damage Mechanism

Based on the observed damages, Type Design 1 and 3 indicated favorable in-plane mechanism. Although, less desirable out-of-plane performance was shown by the Type Designs 2 and 4 models, these were able to maintain strength and stiffness without loss of any element. The reason for in-plane mechanism of Type Design 1 and 3 was the coupled behavior of all the walls due to the integrity provided by RC bands indicating the bands' beneficial role in the overall seismic performance.

Under extreme shaking, all the models exhibited significant sliding and rocking both locally and globally, that helped the structure to undergo large deformation without collapse indicating flexible behavior of the structures. Consequently, the seismic demand on the models reduced significantly. Moreover, the surface containment prevented the dislodging and falling of stones and played role in re-centering of the walls, which is considered excellent performance from the seismic design point of view.

7.3 Energy Dissipation and Structural Damping

The structural damping was calculated from the free vibration tests conducted on the models. The structure displacement response at the eave level was considered and analyzed for calculating decay in the displacement history. The damping was calculated from the logarithmic decay of the last two cycles. All the models possessed significant initial (in the range of 10%) and final structural damping (20 to 30%), due to the multiple cracking and distributed damage over large area of walls. This has been also confirmed by the in-plane quasit-static cyclic tests conducted on wall piers, exhibiting wide and stable hysteretic non-linear response. A structural damping of 8-10% may be conservatively assumed for the elastic response (initial damping) of the model and 20% may be assumed for structure, responding in the inelastic state (final damping).

7.4 Response Modification Factors

For calculation of structural global ductility and yield force, the structure force-deformation capacity curve was bi-linearized as an elasto-plastic curve, based on the energy-balance criterion. The structure's global ductility factor μ was obtained by dividing the ultimate displacement capacity over the idealized yield displacement capacity of structure model. The calculated R factors for tested structures (2.60, 2.61, 2.60 and 2.58 for Type Design 1, 2, 3 and 4, respectively) are almost equal to the Indian Standard, IS: 1893:2016 specified R factors. Consequently, R factor for all Type Designs may be taken as 2.50 for the design and assessment of structures of similar constructions. It should be noted that the drift of the models was constrained close to 2.5% because of limited data available beyond this limit, despite the models survived much higher drift limits. Had the higher drift limits were accounted for, that would have resulted in higher R factors. However, a response modification factors of 2.5 has been recommended for both in-plane and out-of-plane responses of all Type Designs.

7.5 Seismic Performance Levels

Performance based damage scale and strength-deformation capacities in terms of drift limits and base shear coefficients were deduced using the FEMA specified guidelines. The base shear coefficients and drifts limits for all Type Designs are given below:

Type Design	Parameters	Immediate Occupancy	Life Safety	Collapse Prevention
Type Design-1	Drift (%)	0.67	1.85	2.47
	BSC	0.29	0.46	0.37
Type Design -2	Drift (%)	0.72	2.02	2.69
	BSC	0.23	0.36	0.29
Type Design -3	Drift (%)	0.63	1.76	2.34
	BSC	0.34	0.53	0.43
Type Design -4	Drift (%)	0.82	2.25	3.00
	BSC	0.25	0.39	0.31

The values in the above table show that all the Type Designs possess significant deformation and strength capacity corresponding to various occupancy levels.

Additionally, using the Indian Standard IS: 1893-2016, code-based assessment of all Type Designs was carried out through comparison of base shear capacity with the base shear demand obtained from the code specified design acceleration response spectrum corresponding to 5% damping and 8% damping. It may be noted that, initial damping up to 10% was estimated, however, conservatively only 8% damping has been accounted for calculation of BSC. The resulting values are reported as follows:

Type Design	Zone	Level of Seismic Hazard	Zone Factor - Z	Demand BSC** (5% damping) Ah = (Z x I x Sa)/ (2 x R x g) *L. F	Demand BSC** (8% damping)	BSCe	Seismic Performance
Type Design - 1	II	Low	0.1	0.11	0.09	0.46	**OK**
	III	Moderate	0.16	0.18	0.14		**OK**
	IV	Severe	0.24	0.27	0.22		**OK**
	V	Very Severe	0.36	0.41	0.33		**OK**
Type Design - 2	II	Low	0.1	0.11	0.09	0.36	**OK**
	III	Moderate	0.16	0.18	0.14		**OK**
	IV	Severe	0.24	0.27	0.22		**OK**
	V	Very Severe	0.36	0.41	0.33		**OK**
Type Design - 3	II	Low	0.1	0.11	0.09	0.53	**OK**
	III	Moderate	0.16	0.18	0.14		**OK**
	IV	Severe	0.24	0.27	0.22		**OK**
	V	Very Severe	0.36	0.41	0.33		**OK**
Type Design - 4	II	Low	0.1	0.11	0.09	0.39	**OK**
	III	Moderate	0.16	0.18	0.14		**OK**
	IV	Severe	0.24	0.27	0.22		**OK**
	V	Very Severe	0.36	0.41	0.33		**OK**

** Based on calculated R-factor

The comparison shows that Type Designs 1 and 3 can perform satisfactorily at the life safety level in the very severe seismic zone V at code defined 5% damping. A conservatively adopted 8% initial damping would result in all Type Designs compliant at the life safety level as required by IS1893-2016. Consequently, Type Design 2 and Type Design 4 will also be able to perform satisfactorily in the very severe seismic zone V. It should be noted that the code specified 5% damping is typical for reinforced concrete buildings, which poses much lower level of damping than masonry buildings. As reported above, the structural damping calculated from experiments for all the models was in the range of 20% to 30%. This means, once the building has been damaged, this will lead to overdamped system resulting in dissipation of seismic energy as long as building can maintain integrity.

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APPENDIX

Appendix A1 – Preliminary Design Drawings for Prototype

(Type Design 1)

TYPE DESIGN: STONE MASONRY IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY

Material Specification

Masonry

Stone dressing: semi-dressed
Stone dimension: no dimension <150mm
Mortar thickness: 10mm*
Mortar strength: 1-2MPA (cement established, 5-8% of cement, add 10% sand)*
Wall thickness: 400mm (irrespective of whatever is noted in drawings)
Curing:
- masonry: two weeks (could be covered with wet sacks)

Structural Concrete
Concrete compressive strength : 20MPa at 28 days
Concrete cover: 25mm
Concrete production should meet relevant standards

Reinforcing steel

Steel grade: 500MPa
WWM A: Welded wire mesh for stitches: 4mm both directions @ 100x100grids
WWM B: Welded wire mesh for containment: 3mm both directions @ 300x300grids
Reinforcing bars shall be bent cold
Minimum bend diameter for bending bars: 4xbar diameter

Plaster

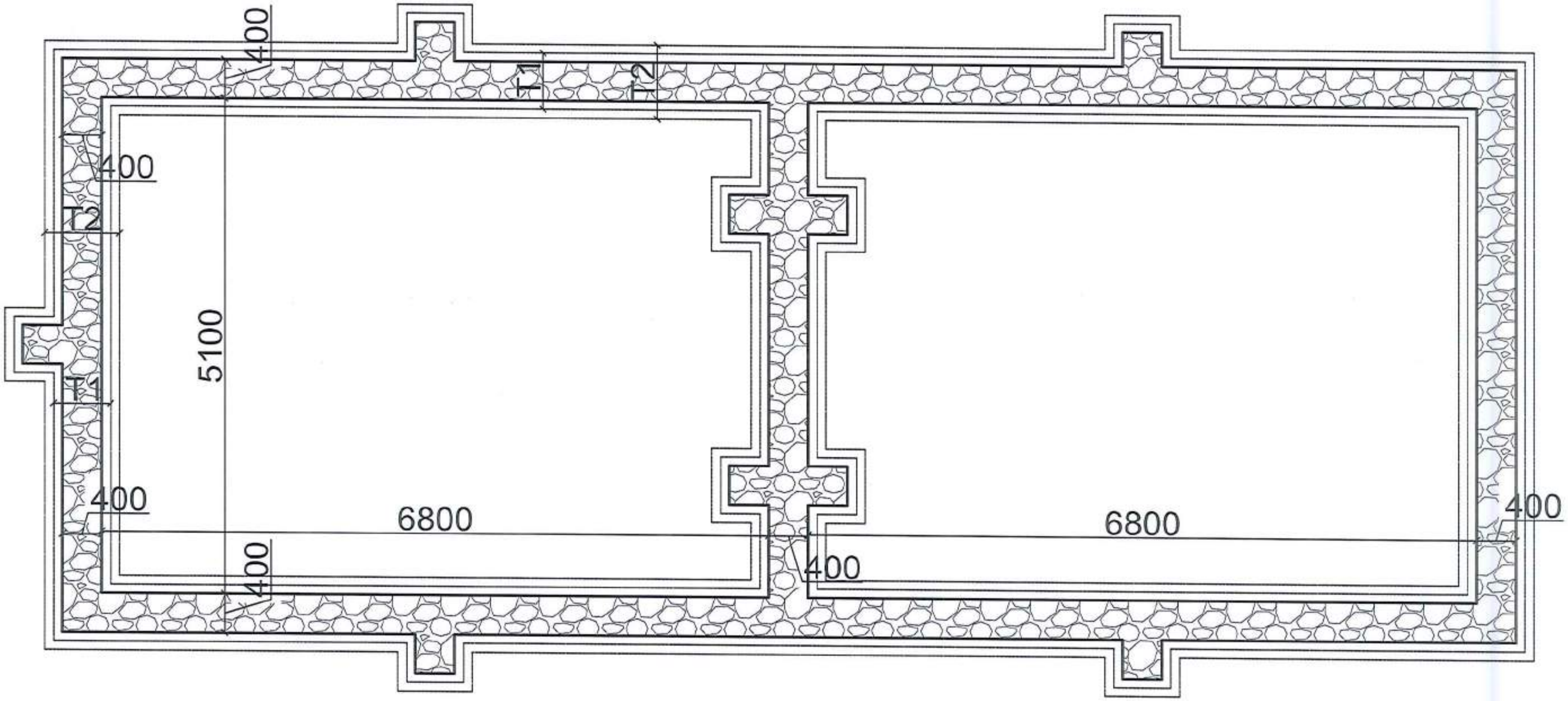
Cement stablised soil plaster

DEVELOPED DESIGN FOR DISCUSSION, FURTHER DEVELOPMENT AND SCALLED MODELLING

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:60	Date:2017-04-28	Sheet No.:
	Drawing Title: General Notes	Design By:		ST-0

TYPE DESIGN: STONE MASONRY IN CEMENT STABILIZED MORTAR AND RCC BANDS

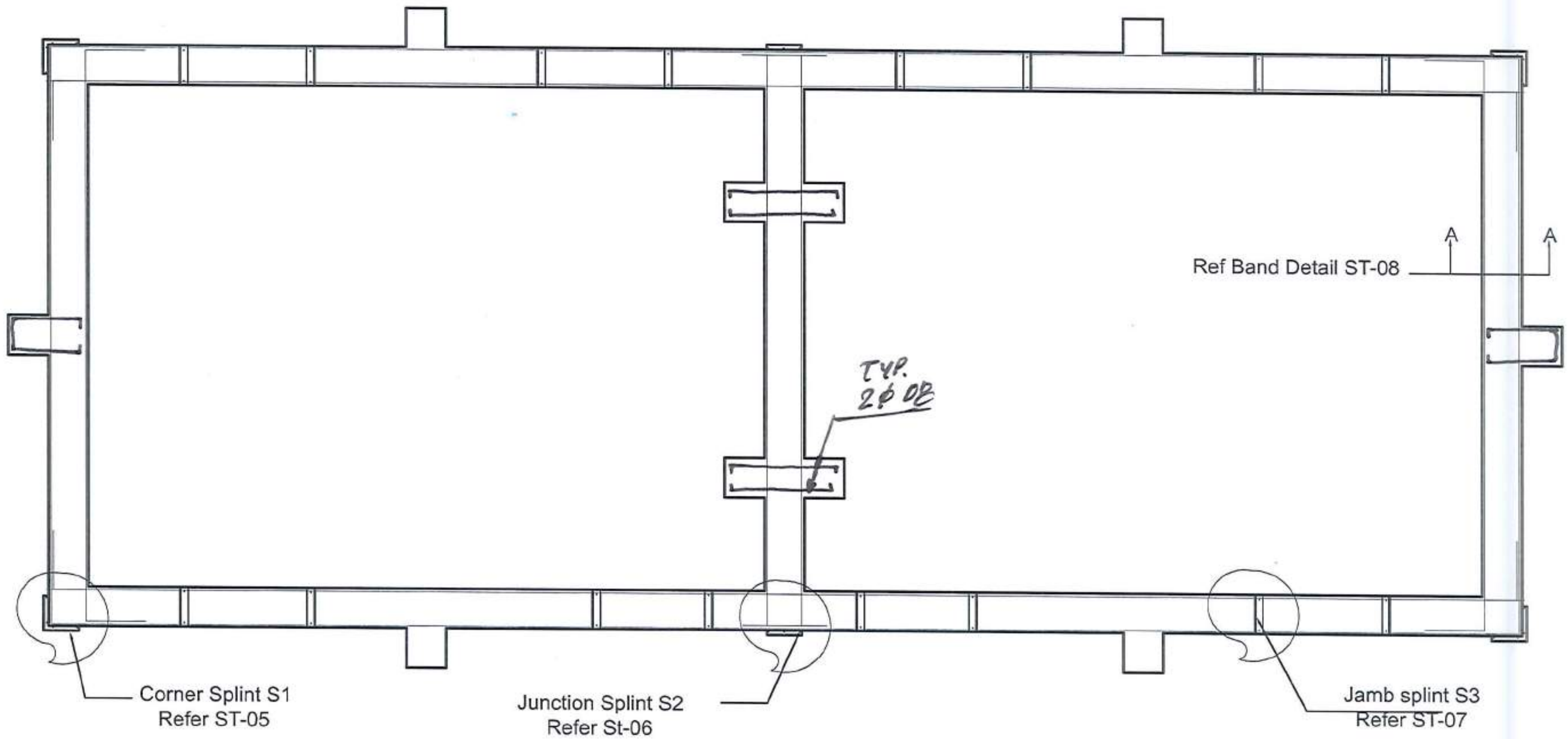
ONE STOREY



Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:50	Date:2017-04-28	Sheet No.:
	Drawing Title:Trench Plan	Design By:		ST-01

TYPE DESIGN: STONE MASONRY IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY



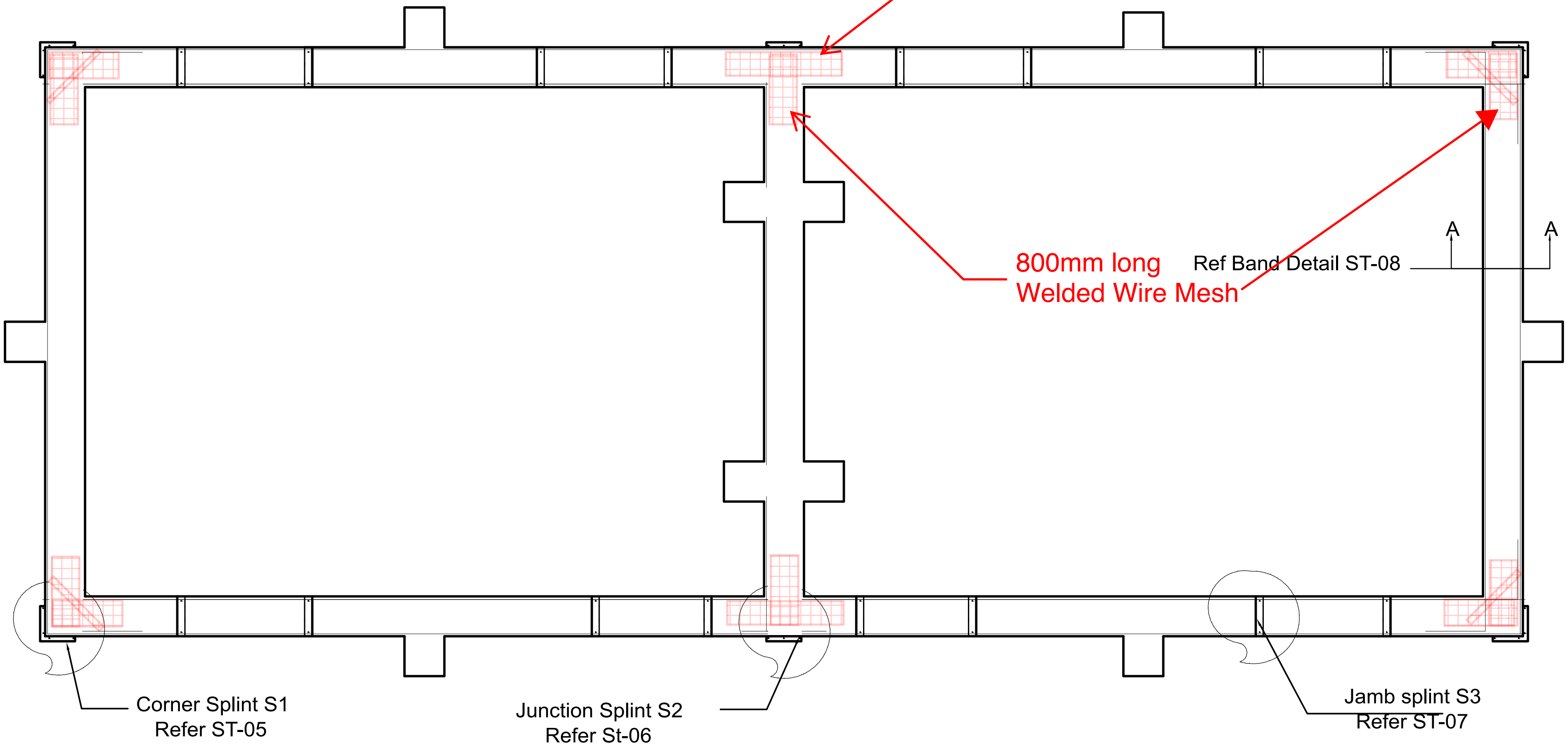
GOAL IS TO REMOVE ATLEAST INTERNAL BUTTRESS.

STIRRUPS NOT SHOWN FOR CLARITY

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:60	Date:2017-04-28	Sheet No.:
	Drawing Title:Plan with Band and vertical bars ✓	Design By:		ST-02

TYPE DESIGN: STONE MASONRY IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY

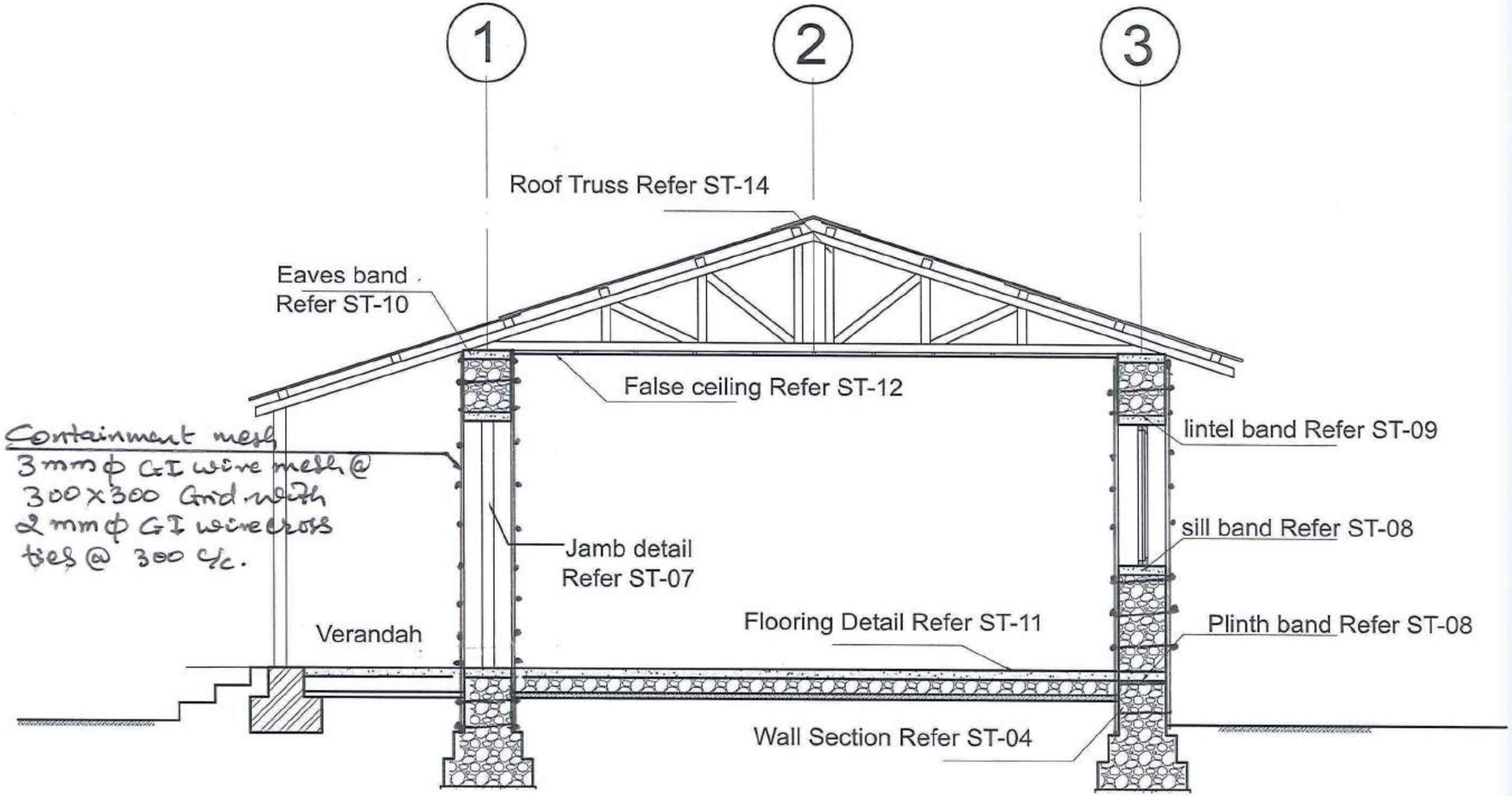


- Welded Wire Mesh (WWM) placed between DPC and Sill Level, and Sill and Lintel Level, Ref Ar03 and Ar04
- WWM embedded in the mortar layer

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:60	Date:2017-04-28	Sheet No.:
	Drawing Title: Stitch deatils	Design By:		ST-02.01

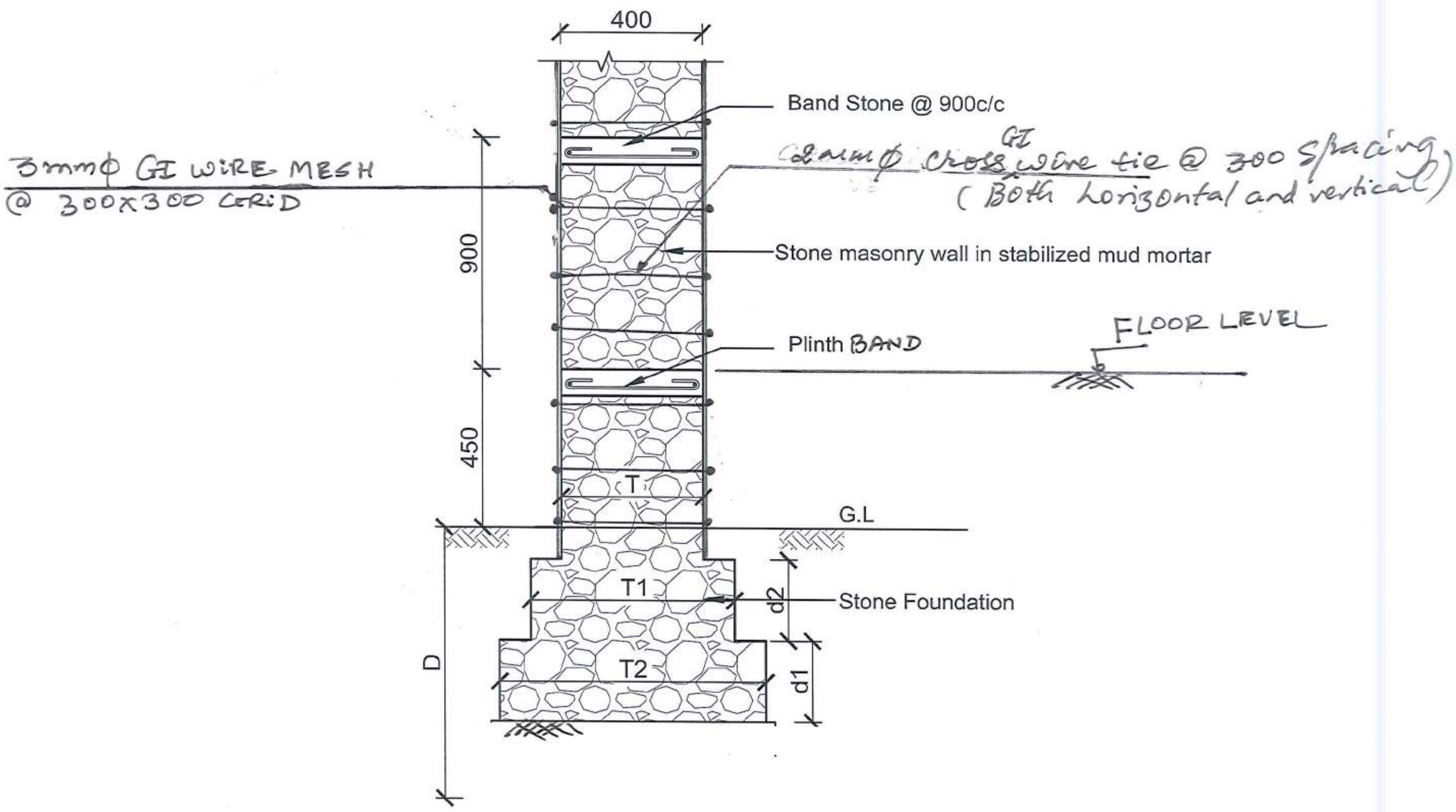
TYPE DESIGN: STONE MASONRY IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY



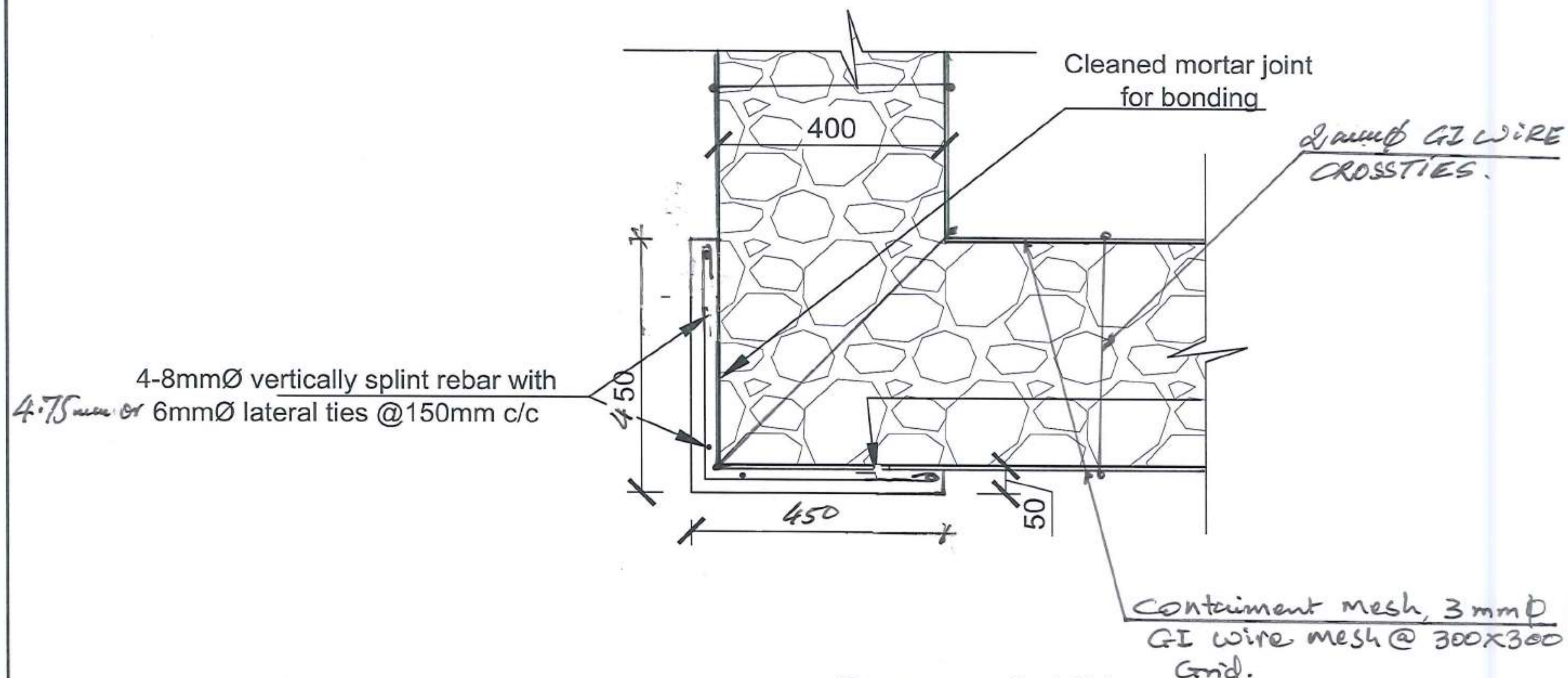
Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:50	Date:2017-04-28	Sheet No.:
	Drawing Title: Structural Section	Design By:		ST-03

TYPE DESIGN: STONE MASONRY IN CEMENT STABILIZED MORTAR AND RCC BANDS | ONE STOREY



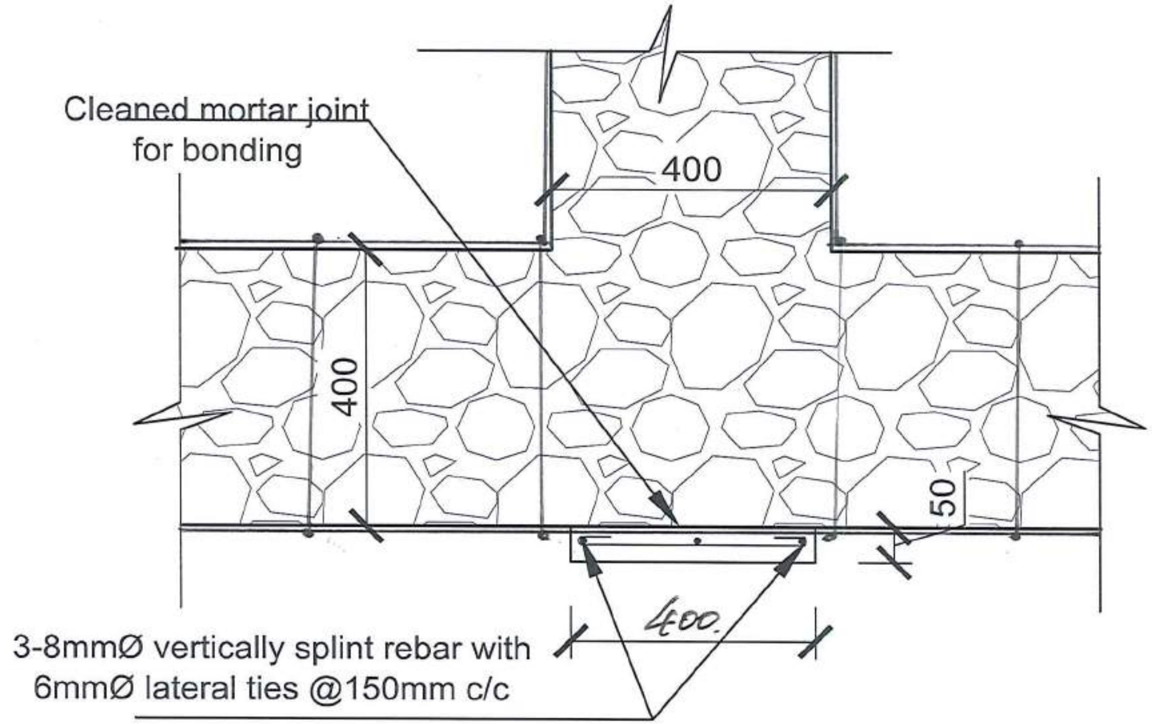
Wall Section (Foundation)

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:15	Date:2017-04-28	Sheet No.:
	Drawing Title:Wall Section Detail	Design By:		ST-04



Corner splint S1

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:10	Date:2017-04-28	Sheet No.:
	Drawing Title:Corner Splint Detail	Design By:		ST-05

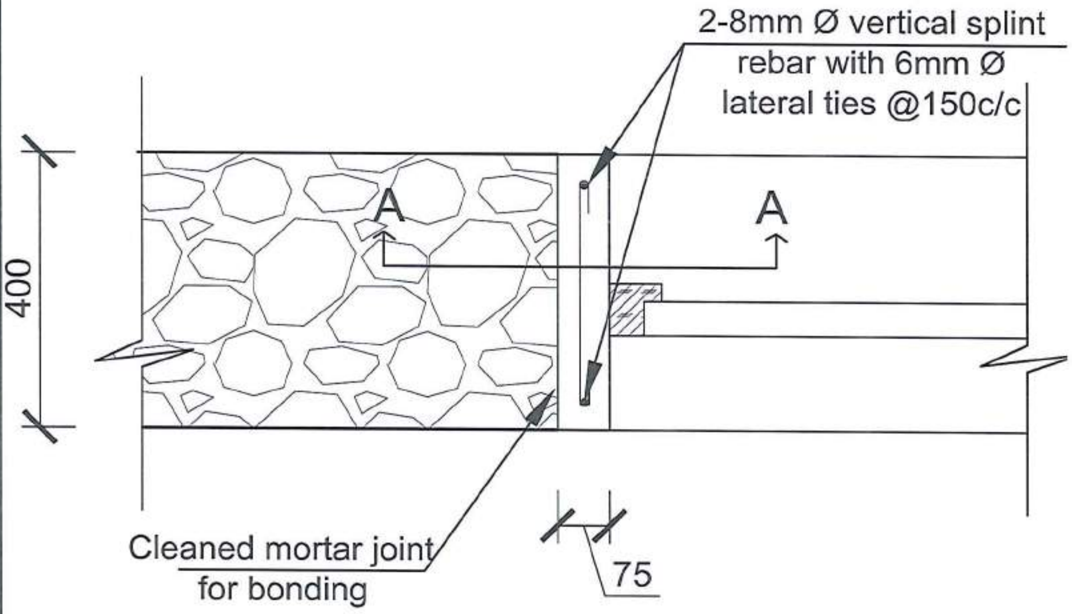


T- Junction Splint S2

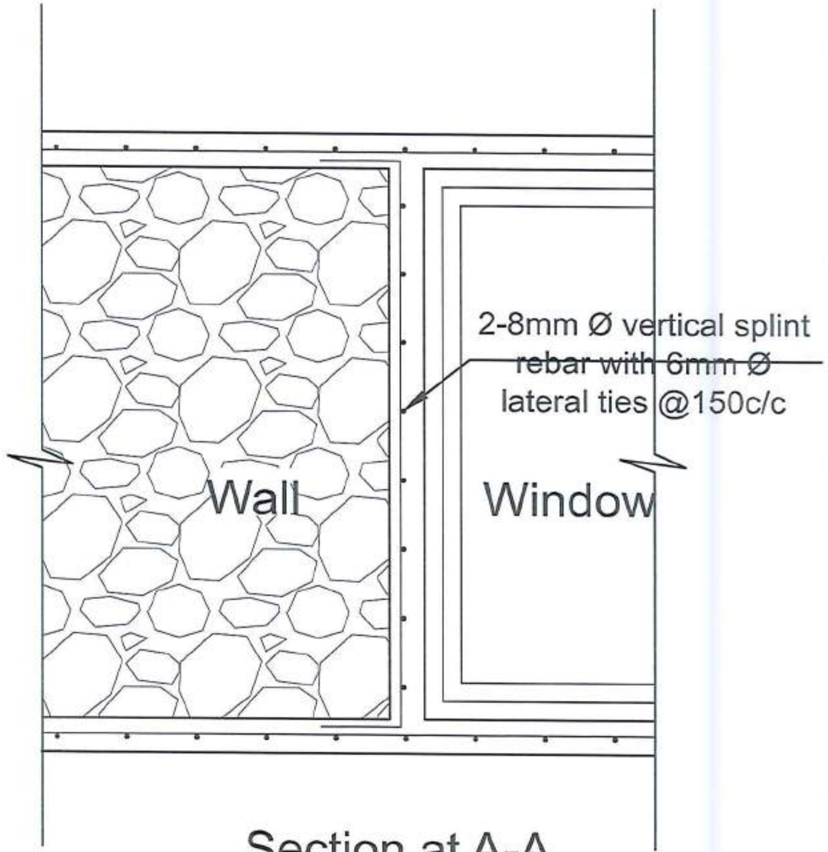
Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:10	Date:2017-04-28	Sheet No.: ST-06
	Drawing Title:T-Junction Splint Detail	Design By:		

TYPE DESIGN: STONE MASONRY IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY



Jamb Splint S3

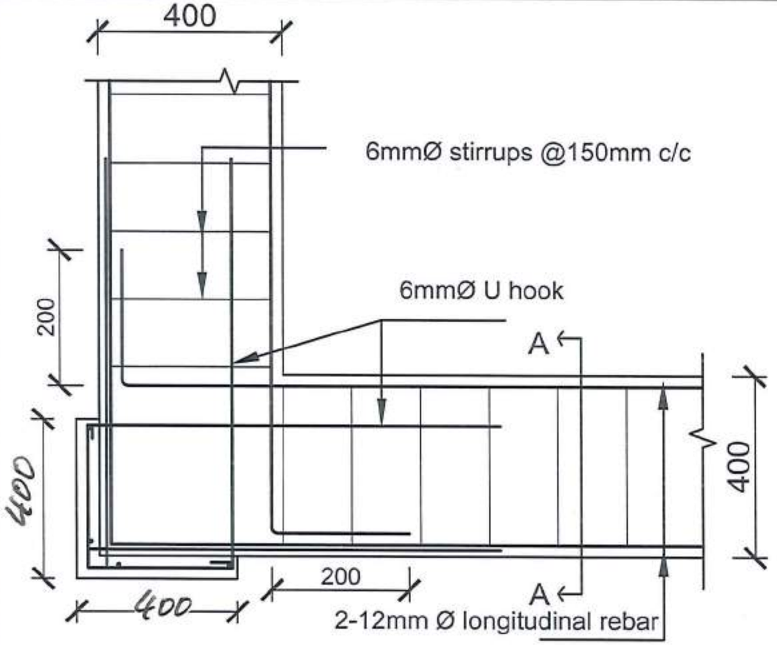


Section at A-A

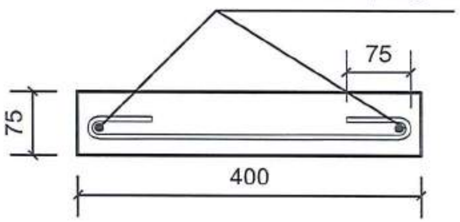
Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:10	Date:2017-04-28	Sheet No.: ST-07
	Drawing Title:Jamb Splint Detail	Design By:		

TYPE DESIGN: STONE MASONRY IN CEMENT STABILIZED MORTAR AND RCC BANDS

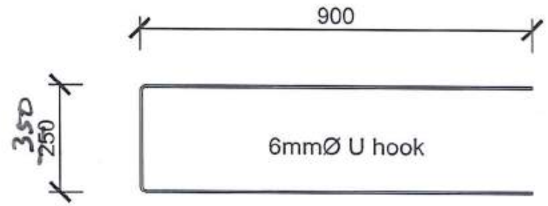
ONE STOREY

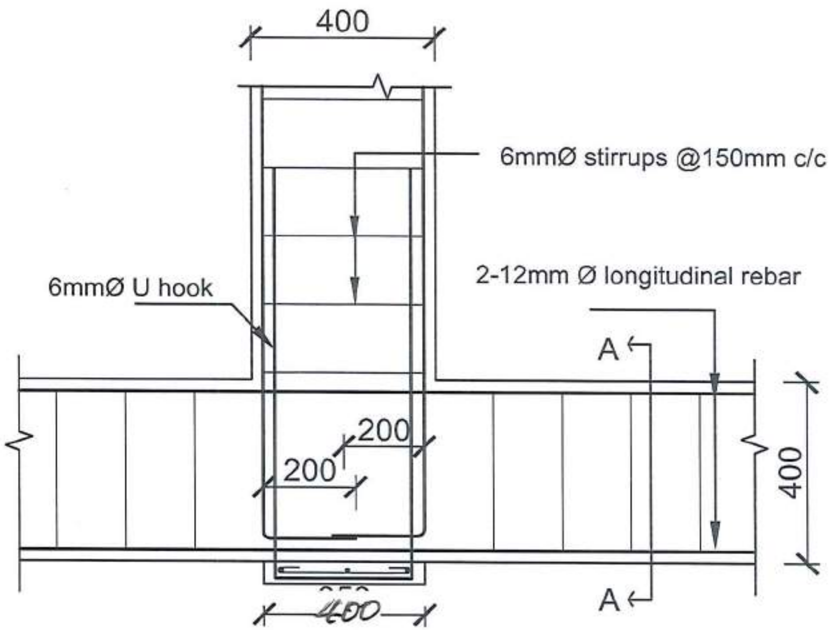


corner junction



Section at A-A
Plinth, Sill band
(SCALE 1:8)





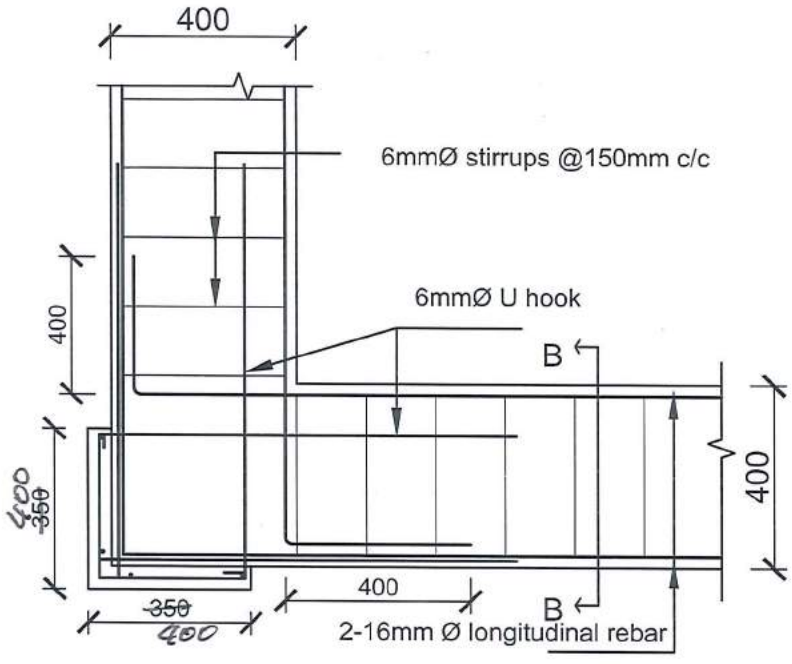
T- junction

CONTAINMENT MESH NOT SHOWN FOR CLARITY

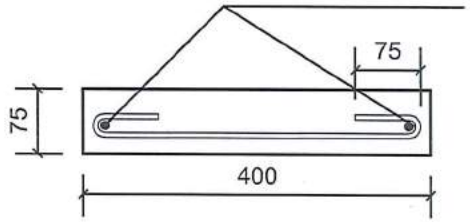
Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:15	Date:2017-04-28	Sheet No.:
	Drawing Title:Plinth, Sill Band Detail	Design By:		ST-08

TYPE DESIGN: STONE MASONRY IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY

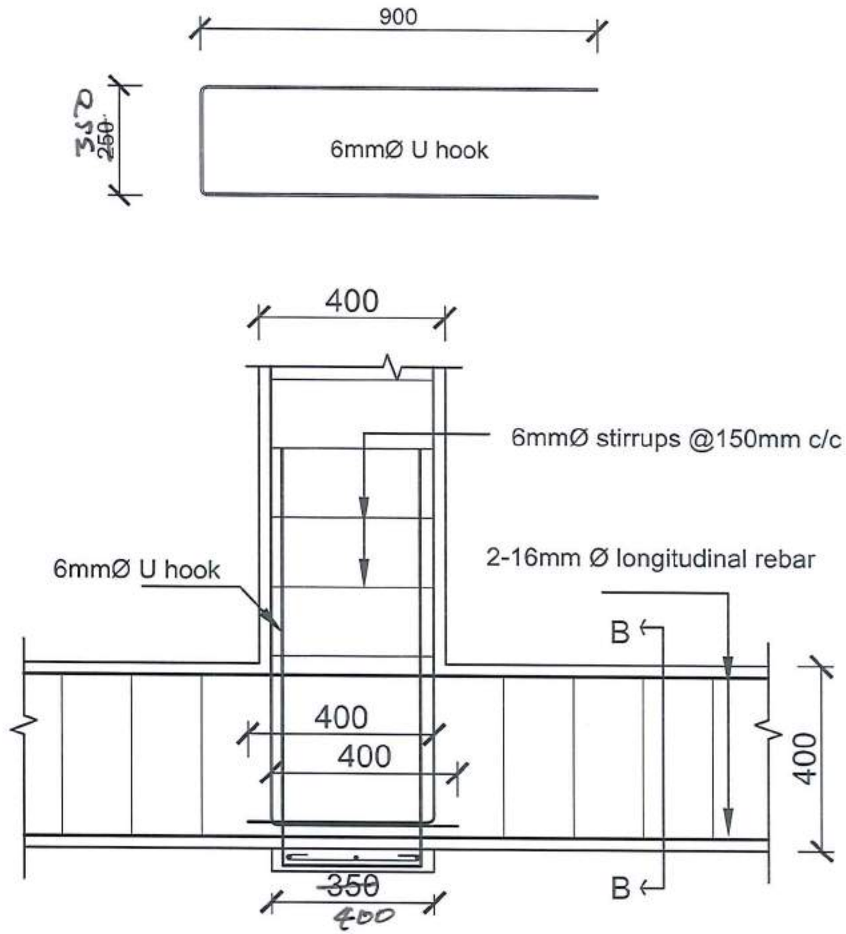


corner junction



Section at B-B Lintel band

(SCALE 1:8)

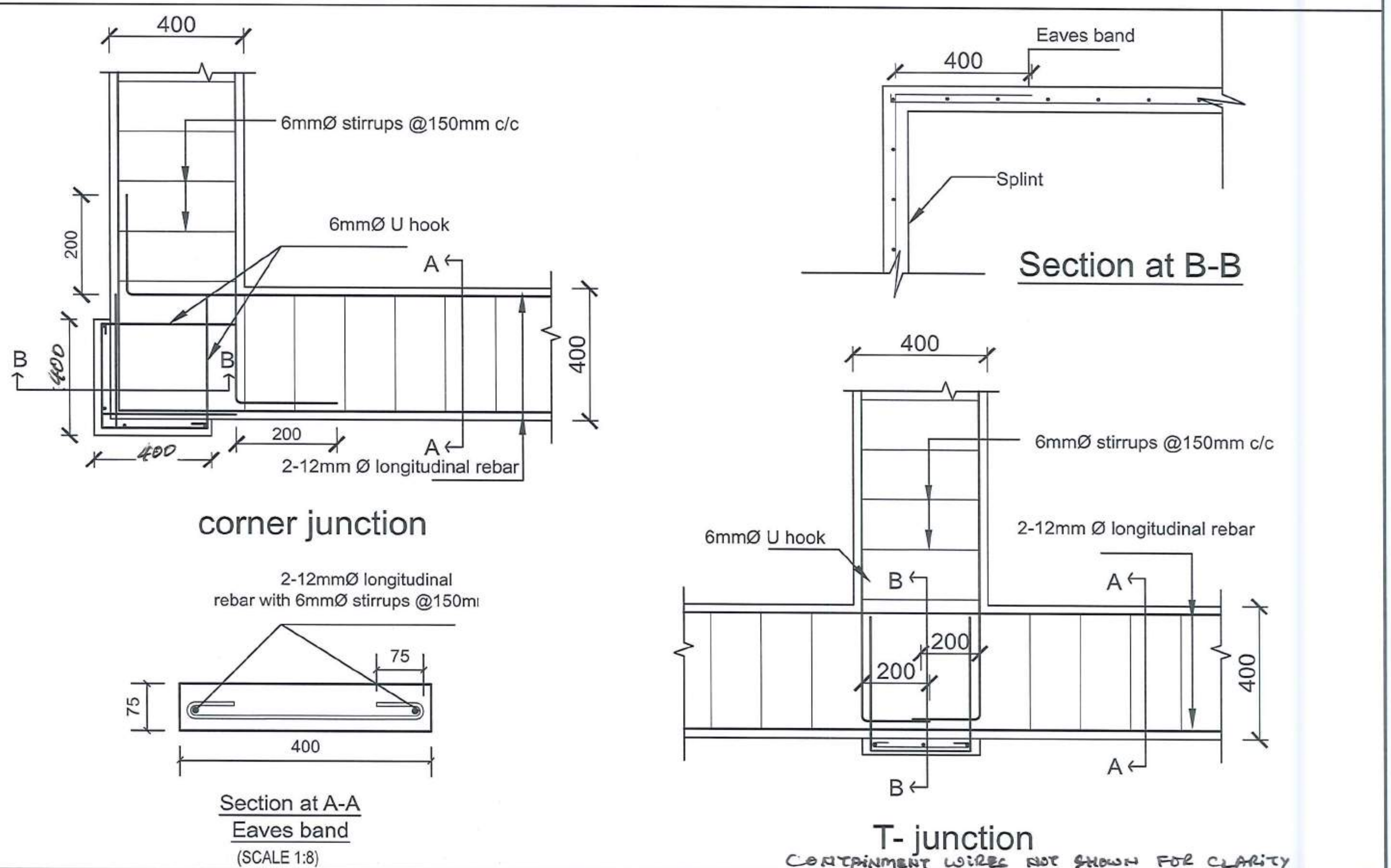


T- junction

CONTAINMENT WIRES NOT SHOWN FOR CLARITY

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:15	Date:2017-04-28	Sheet No.:
	Drawing Title:Lintel Band Detail	Design By:		ST-09

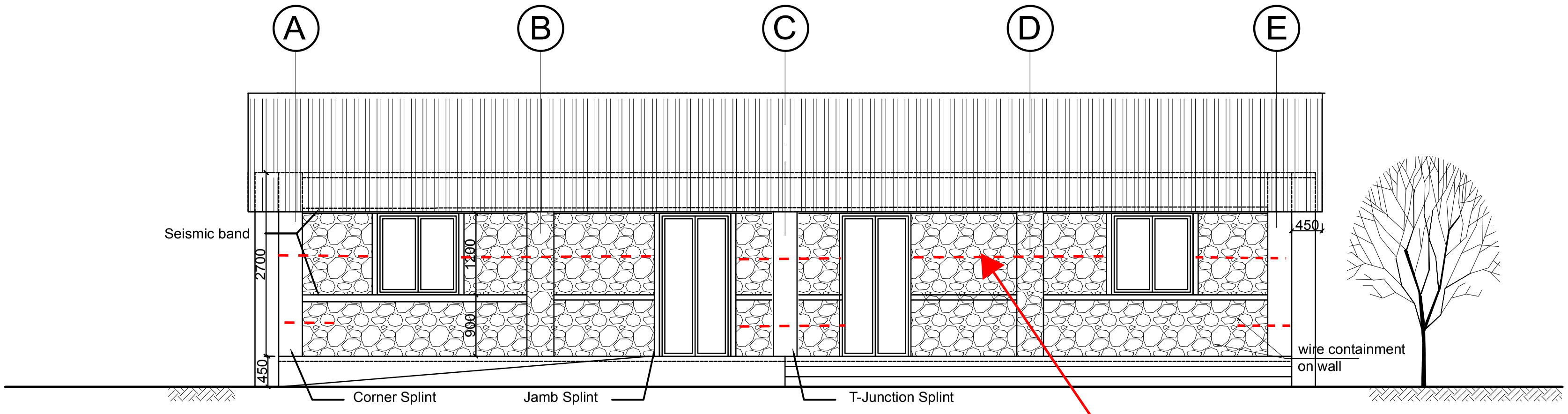
TYPE DESIGN: STONE MASONRY IN CEMENT STABILIZED MORTAR AND RCC BANDS | ONE STOREY



Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:15	Date:2017-04-28	Sheet No.: ST-10
	Drawing Title:Eaves Band Detail	Design By:		

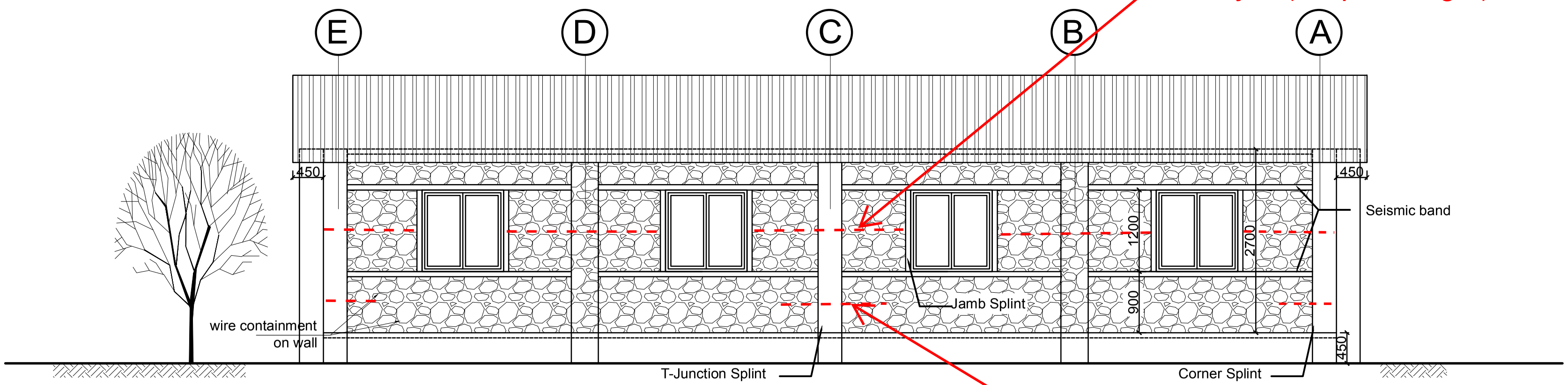
TYPE DESIGN: STONE MASONRY IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY



FRONT ELEVATION
(Grid 1-1)

WWM A embedded in mortar layer (full pier length)



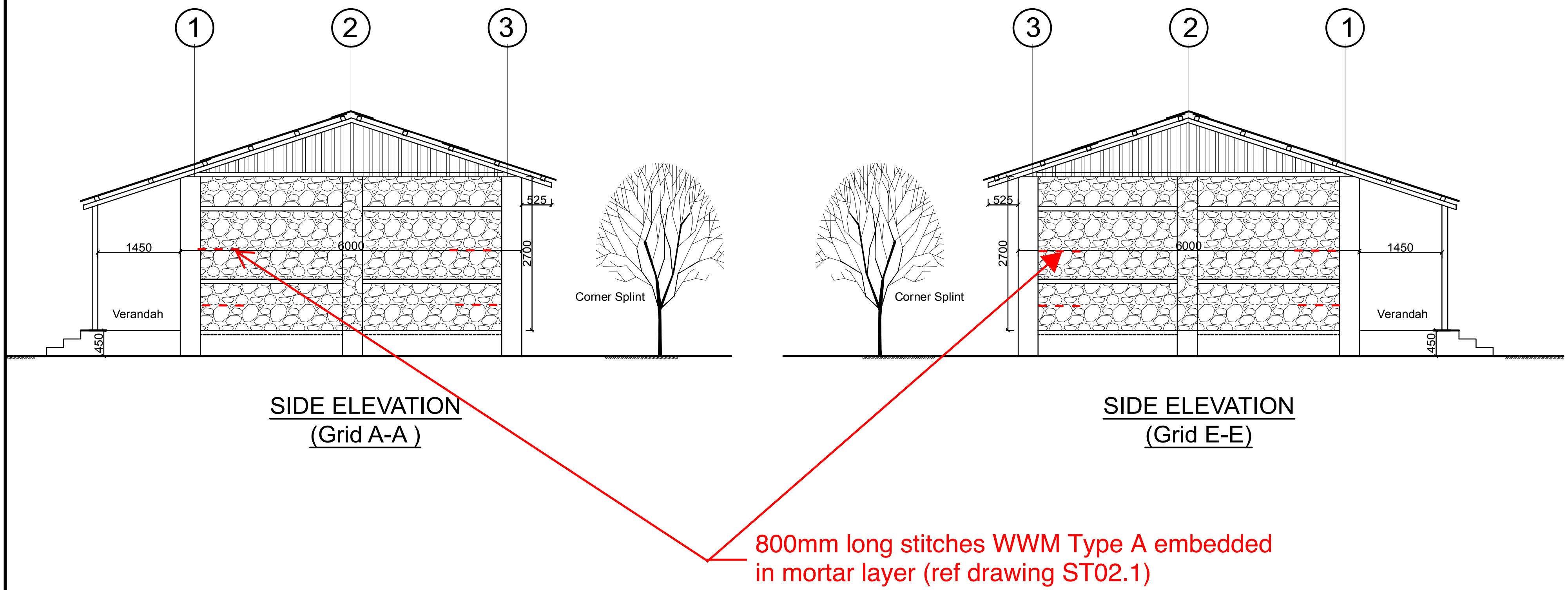
BACK ELEVATION
(Grid 3-3)

WWM Type A stitches embedded in mortar layer (ref drawing ST02.1)

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:100	Date:2017-04-28	Sheet No.:
	Drawing Title: Stitches	Design By:		AR-03

TYPE DESIGN: STONE MASONRY IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY



SIDE ELEVATION
(Grid A-A)

SIDE ELEVATION
(Grid E-E)

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:100	Date:2017-04-28	Sheet No.:
	Drawing Title:Elevations	Design By:		AR-04

Appendix A2 – Preliminary Design Drawings for Prototype (Type Design 2)

Type 2: Block stone masonry with Gabion mesh/Geogrid bands and wire containment ONE STOREY

Material Specification

Masonry
Stone dressing: semi-dressed
Stone dimension: no dimension <150mm
Mortar thickness: 10mm*
Mortar strength: 1-2MPA (cement established, 5-8% of cement, add 10% sand)*
Wall thickness: 400mm (irrespective of whatever is noted in drawings)
Curing:
- masonry: two weeks (could be covered with wet sacks)

Masonry compressive strength = 1.8MPa
Masonry tensile strength = 0MPa
Masonry Young's Modulus = 350MPa

Structural Concrete
Concrete compressive strength : 20MPa at 28 days
Concrete cover: 25mm
Concrete production should meet relevant standards

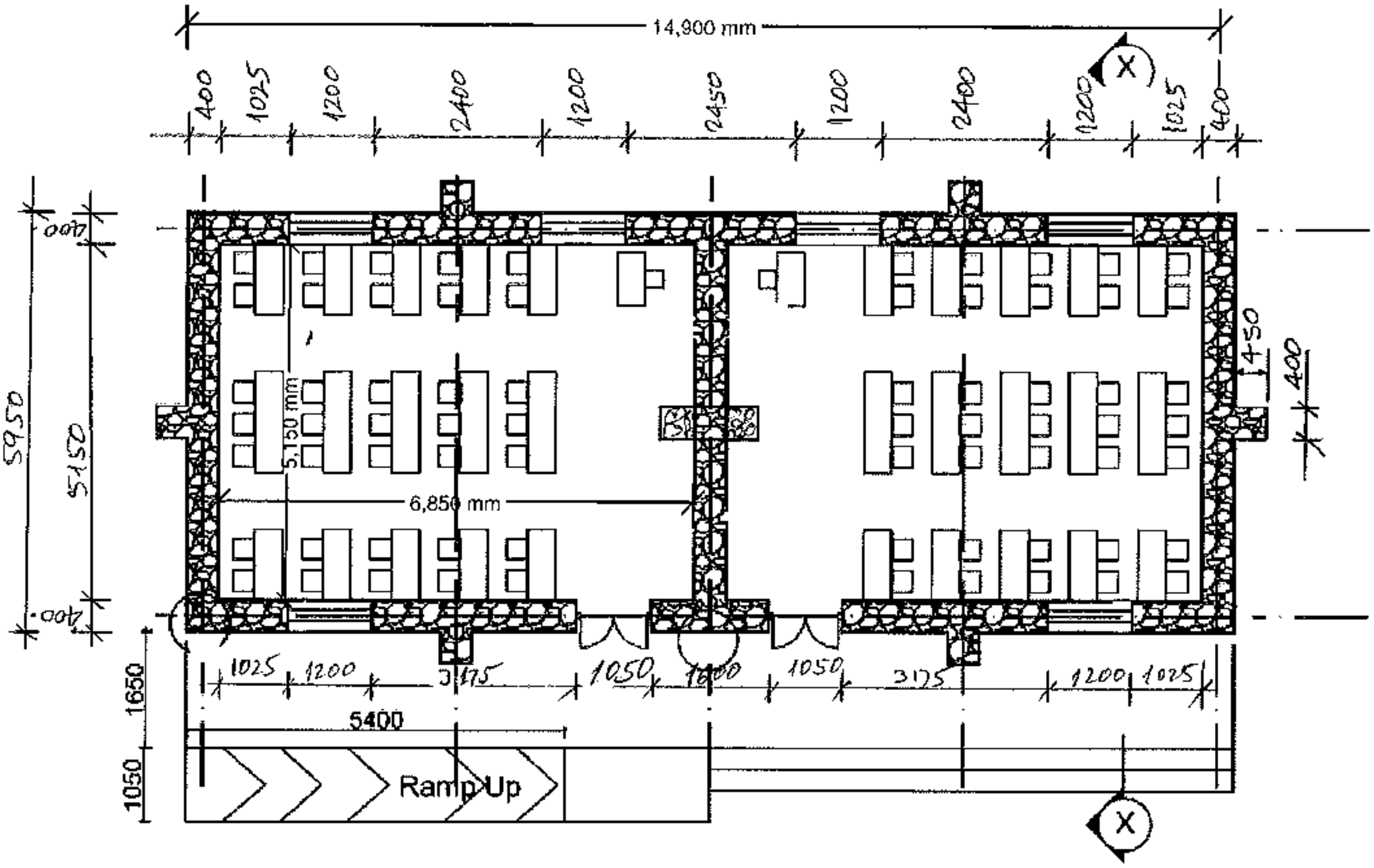
Reinforcing steel
Steel grade: 500MPa
WWM A: Welded wire mesh for stitches: 4mm both directions @ 100x100grids
WWM B: Welded wire mesh for containment: 3mm both directions @ 300x300grids
Reinforcing bars shall be bent cold
Minimum bend diameter for bending bars: 4xbar diameter

Plaster
Cement stablised soil plaster

SWG Wires
Yield strength: 380MPa

DEVELOPED DESIGN FOR DISCUSSION, FURTHER DEVELOPMENT AND SCALLED MODELLING

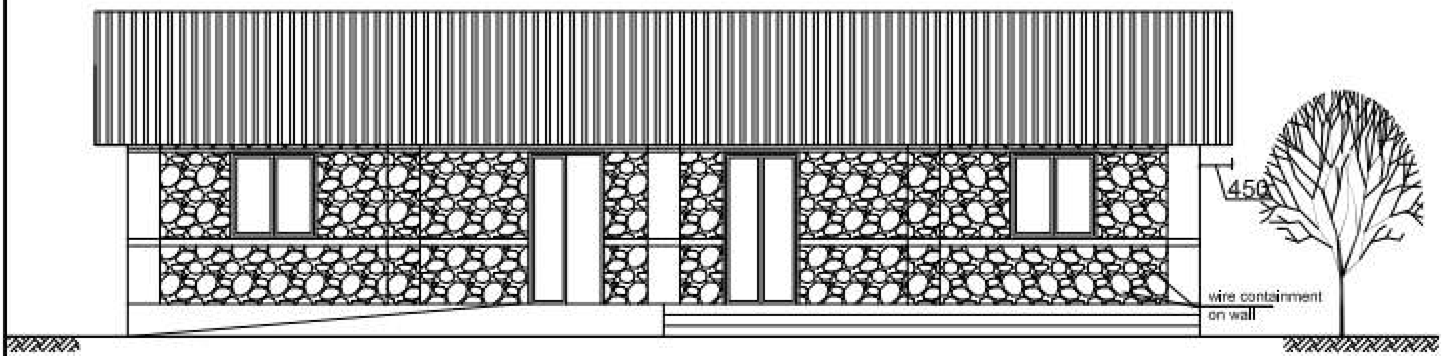
Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale:	Date: 2017/10/01	Sheet No.:
	Drawing Title: General Notes	Design By:		ST-0



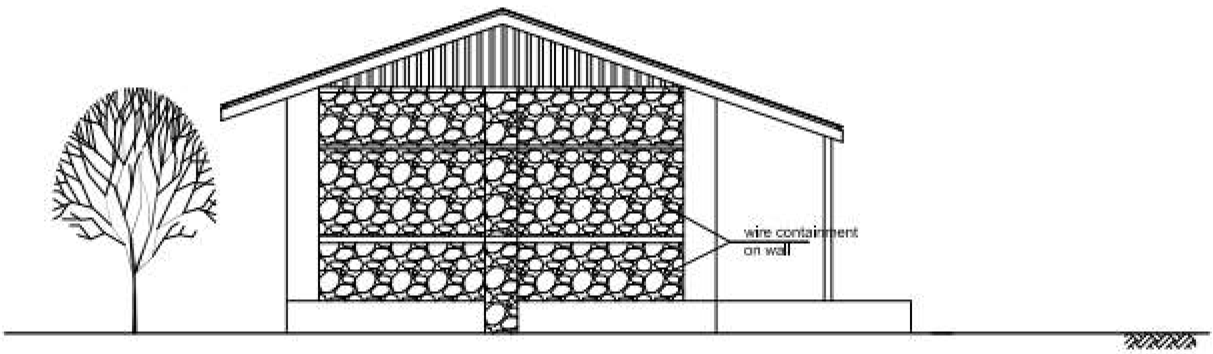
PLAN (2 rooms)

Note: The drawings are only for discussion not construction.

Type 2: Block stone masonry with Gabion mesh/Geogrid bands and wire containment



FRONT ELEVATION

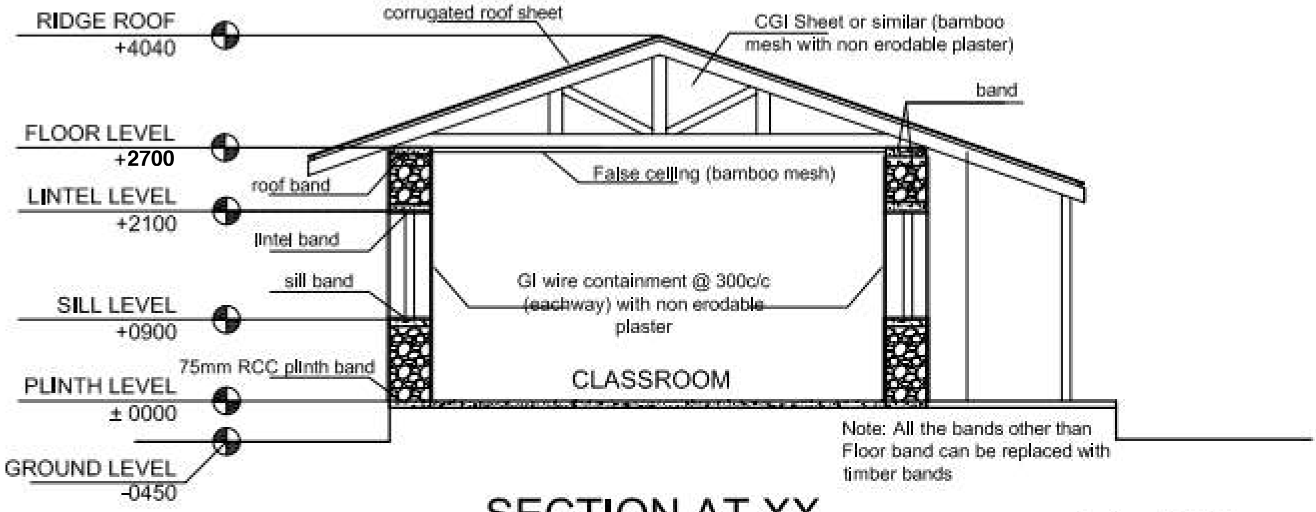


SIDE ELEVATION

Scale -1:2500

Note: The drawings are only for discussion not construction.

Type 2: Block stone masonry with Gabion mesh/Geogrid bands and wire containment



SECTION AT XX

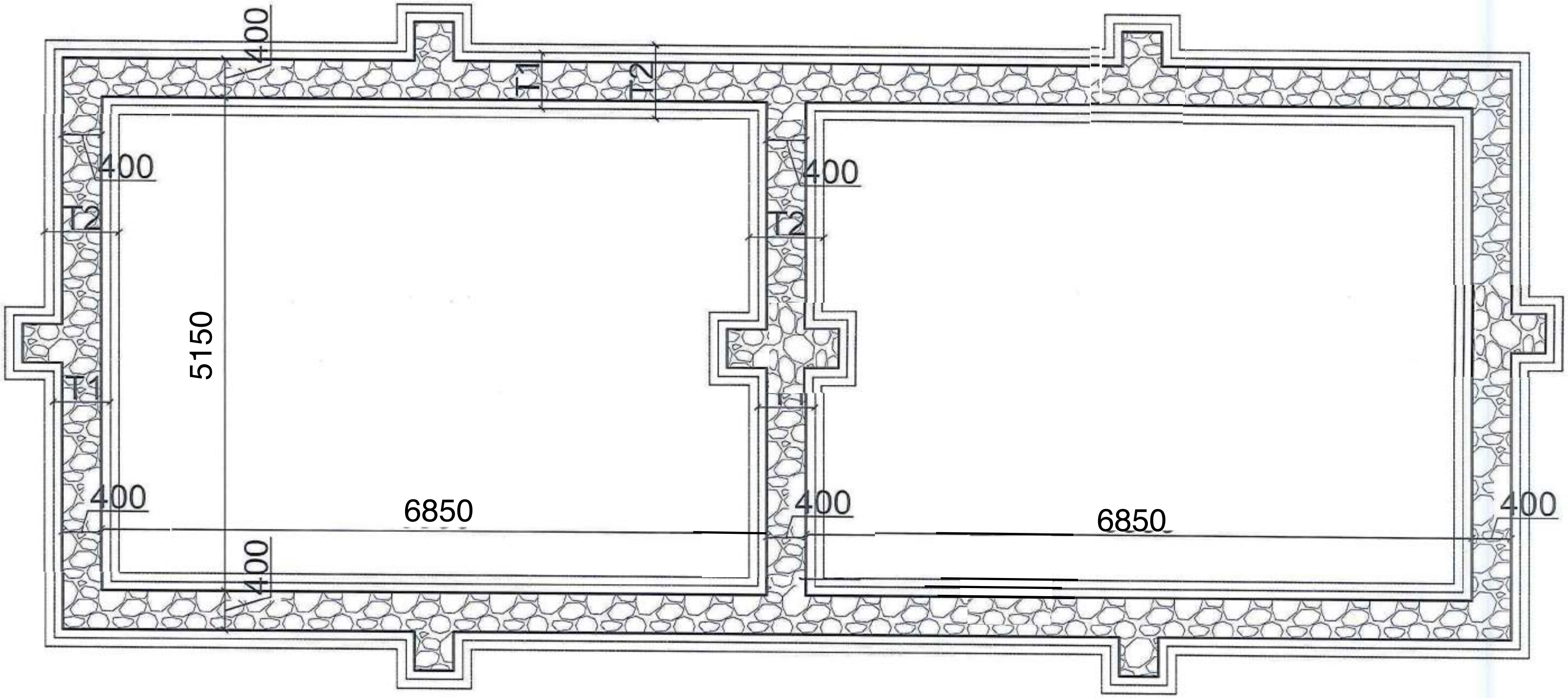
Scale -1:2000

Note: The drawings are only for discussion not construction.

Type 2: Block stone masonry with Gabion mesh/Geogrid bands and wire containment

Type 2: Block stone masonry with Gabion mesh/Geogrid bands and wire containment

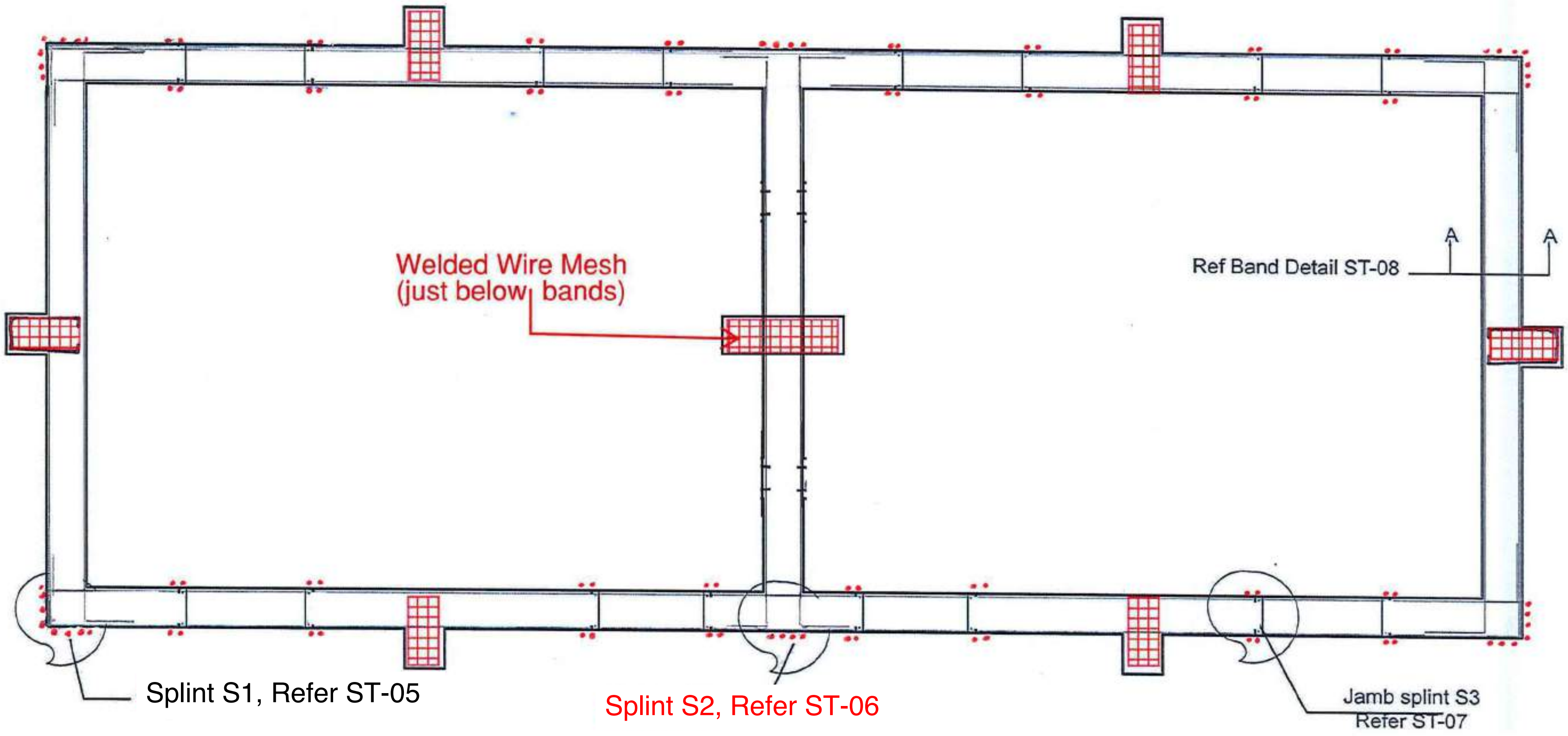
ONE STOREY



Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:50	Date:2017-04-28	Sheet No.:
	Drawing Title:Trench Plan	Design By:		ST-01

Type 2: Block stone masonry with Gabion mesh/Geogrid bands and wire containment

ONE STOREY



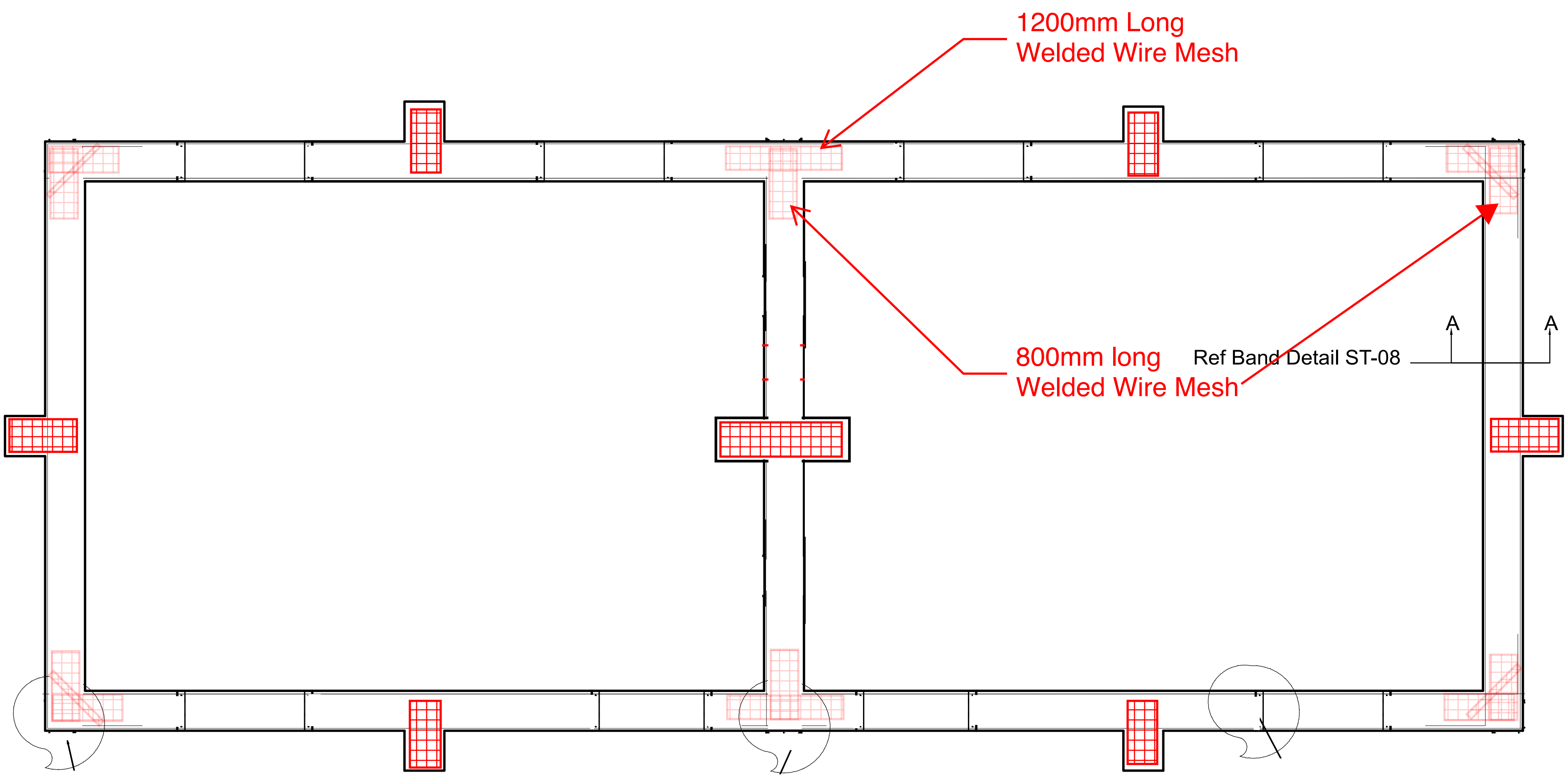
- Containment wires not shown for clarity
- Plinth band stirrups not shown for clarity
- Wires shown for splints are representative only
- If structurally possible, remove internal buttresses

Provide buttresses stitches at:
- Plinth, sill, lintel and eaves level
- Between plinth and sill
- Between lintel and eaves level

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale:	Date:	Sheet No.:
	Title: Plinth band, vertical wires at wall junctions, jambs, and buttresses stitches	Design By:		ST-02

Type 2: Block stone masonry with Gabion mesh/Geogrid bands and wire containment

ONE STOREY

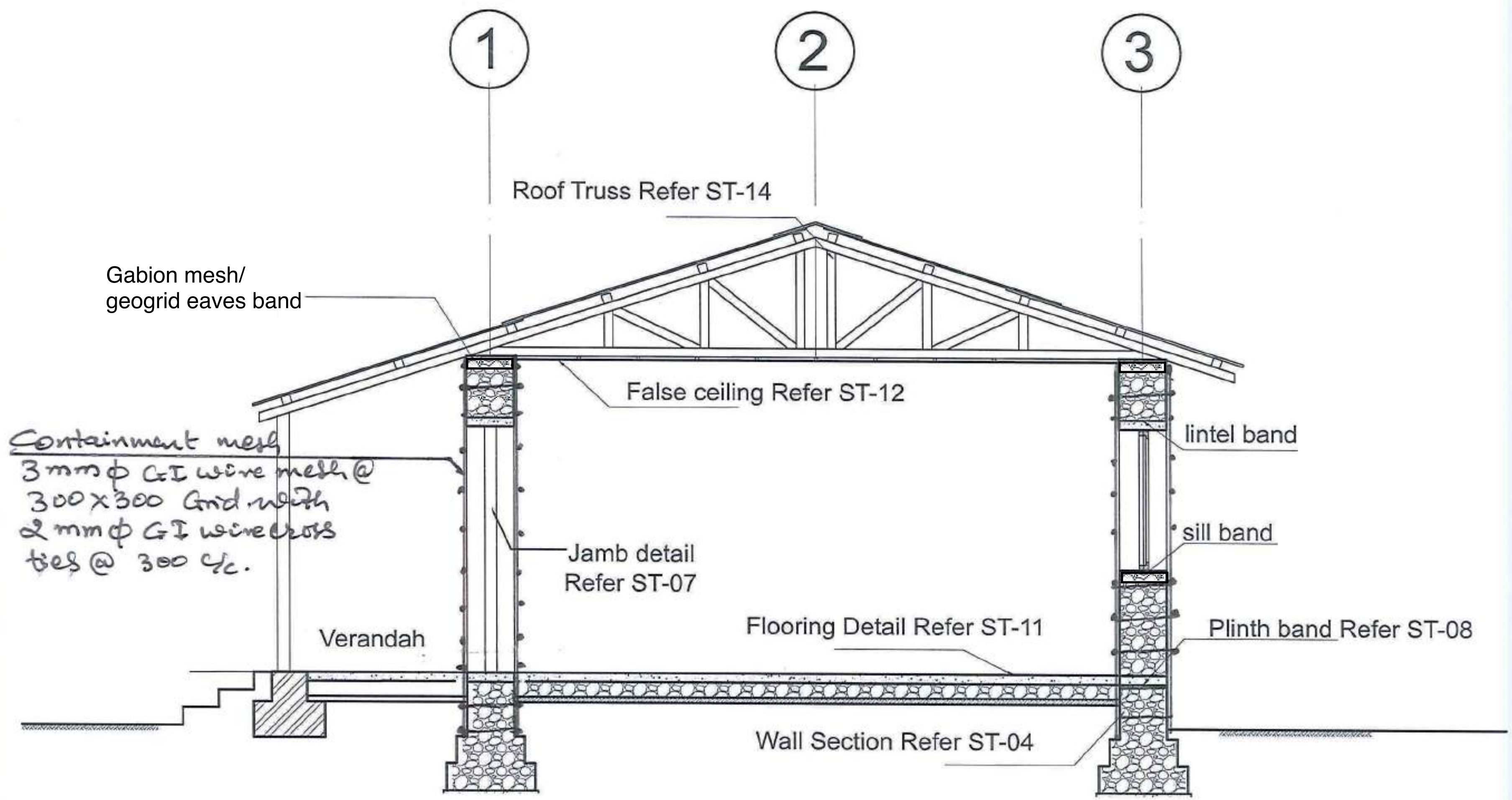


- Welded Wire Mesh (WWM) placed between DPC and Sill Level, and Sill and Lintel Level, Ref Ar03 and Ar04
- WWM embedded in the mortar layer

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale:	Date:	Sheet No.:
	Drawing Title: Stitch deatils	Design By:		ST-02.

Type 2: Block stone masonry with Gabion mesh/Geogrid bands and wire containment

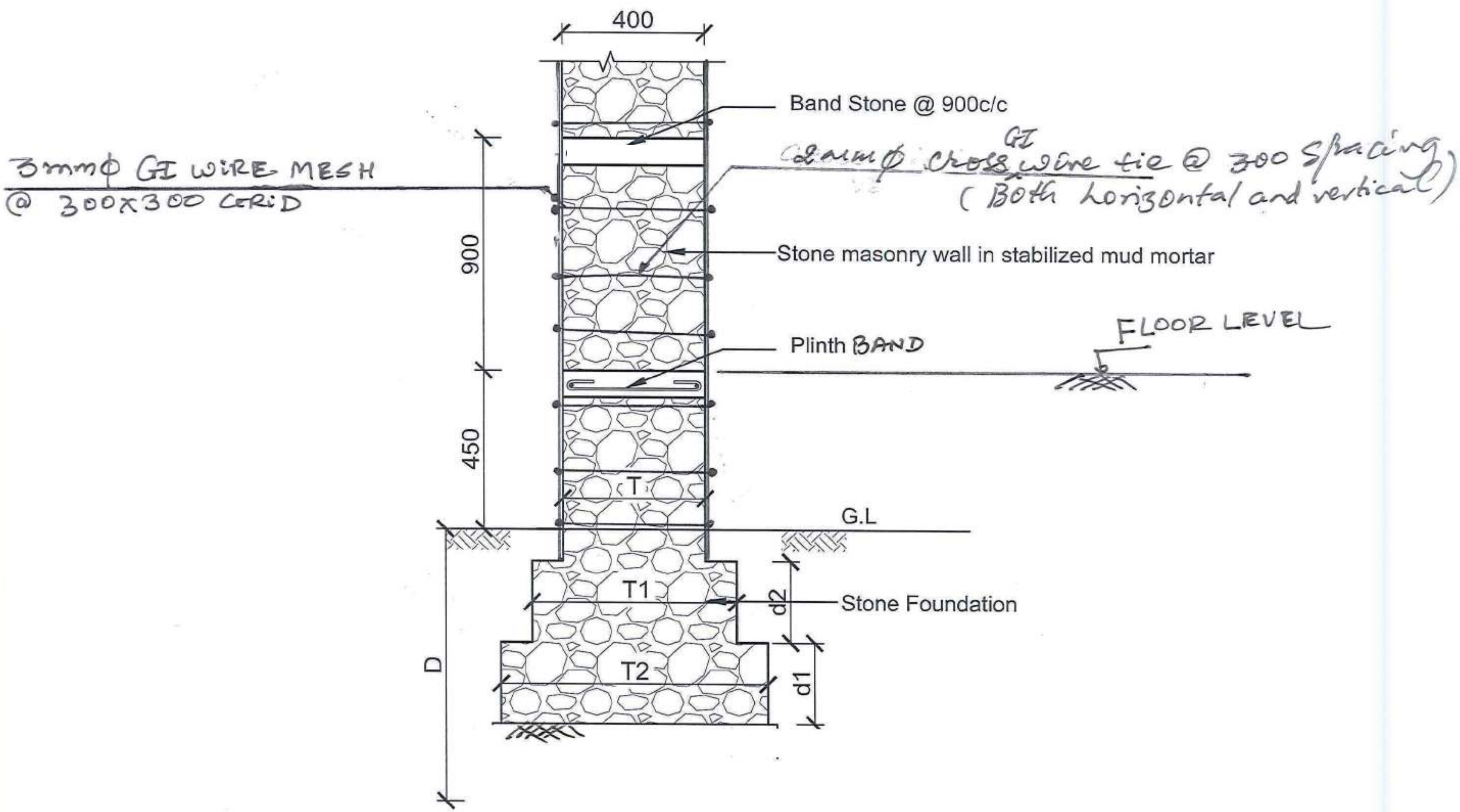
ONE STOREY



Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale:	Date:	Sheet No.: ST-03
	Drawing Title: Structural Section	Design By:		

Type 2: Block stone masonry with Gabion mesh/Geogrid bands and wire containment

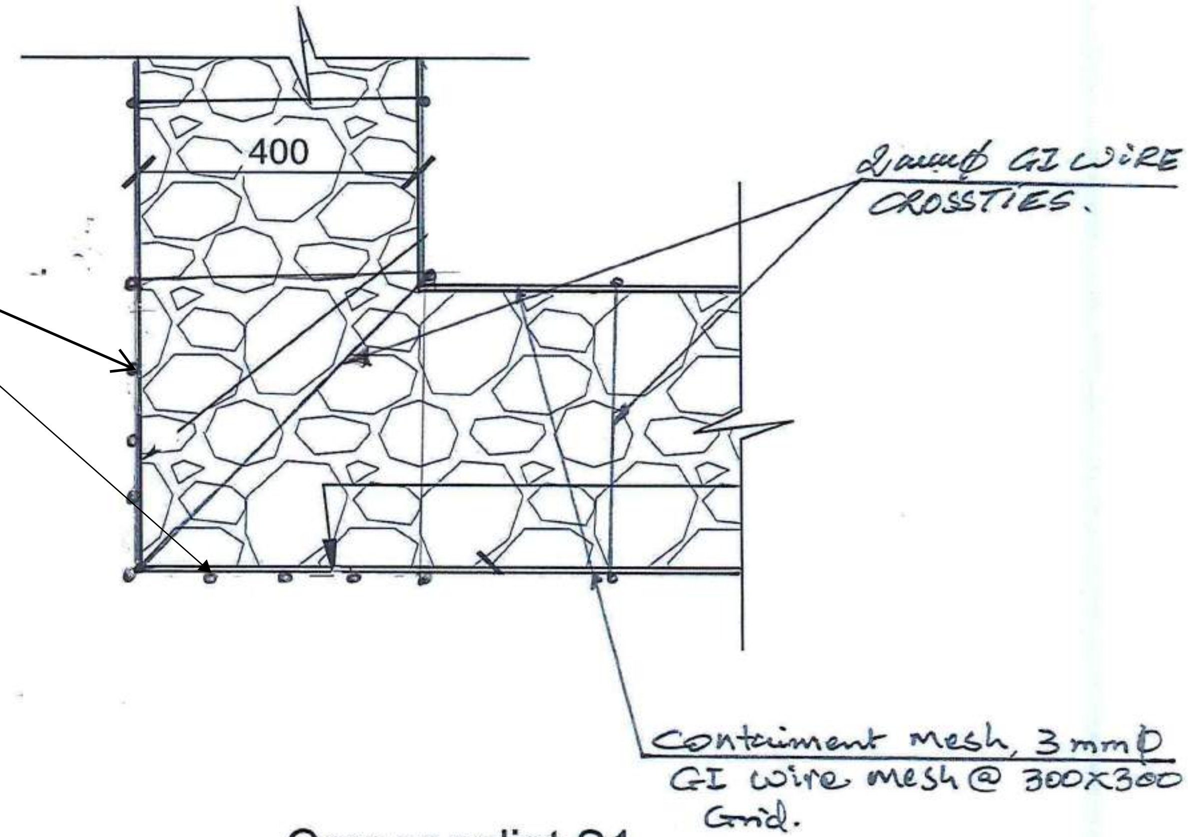
ONE STOREY



Wall Section (Foundation)

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale:	Date:	Sheet No.: ST-04
	Drawing Title:Wall Section Detail	Design By:		

Type 2: Block stone masonry with Gabion mesh/Geogrid bands and wire containment ONE STOREY

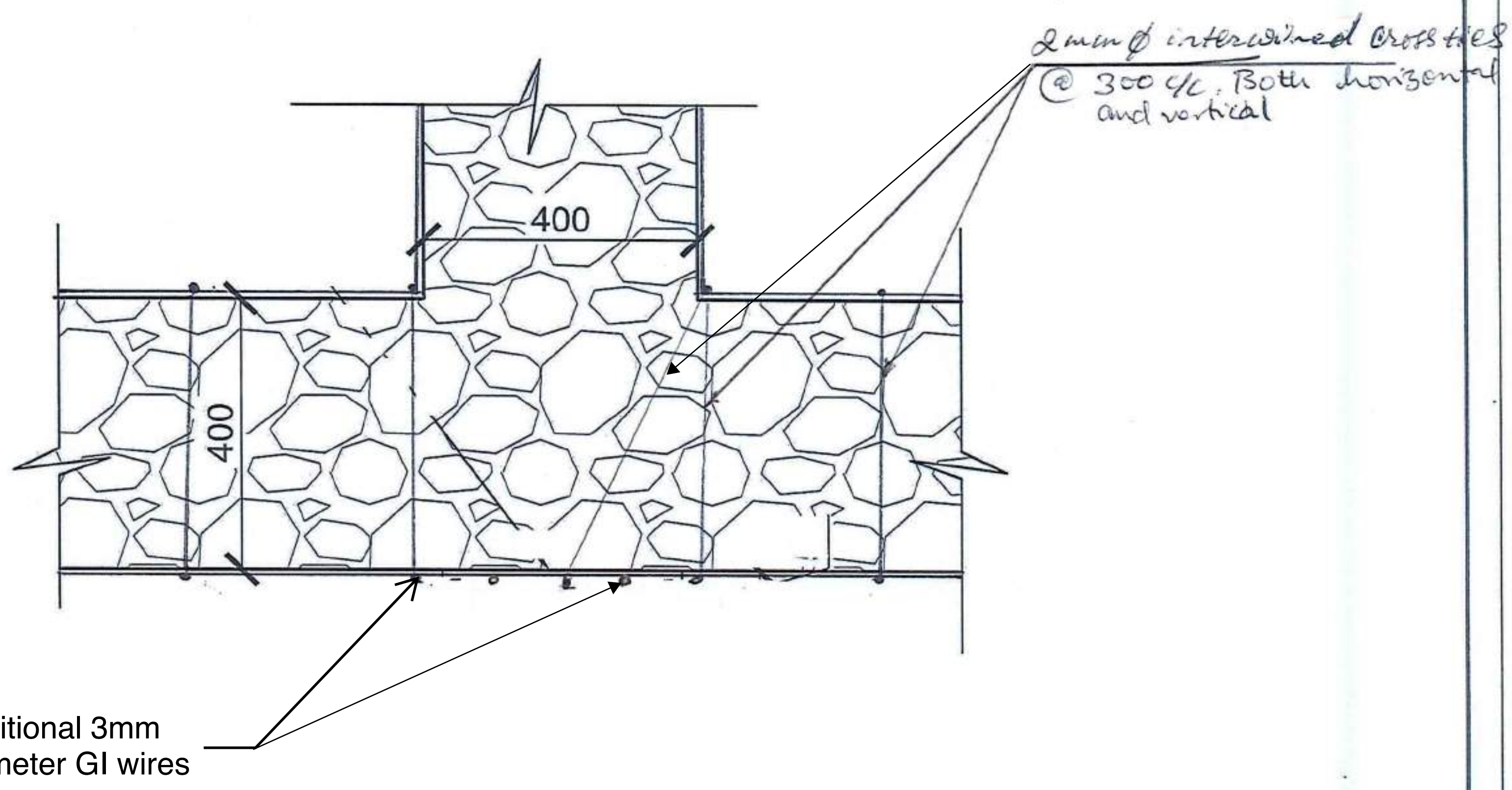


Corner splint S1

- Wires shown for splints are representative only

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:10	Date:2017-04-28	Sheet No.:
	Drawing Title:Corner Splint Detail	Design By:		ST-05

Type 2: Block stone masonry with Gabion mesh/Geogrid bands and wire containment **ONE STOREY**



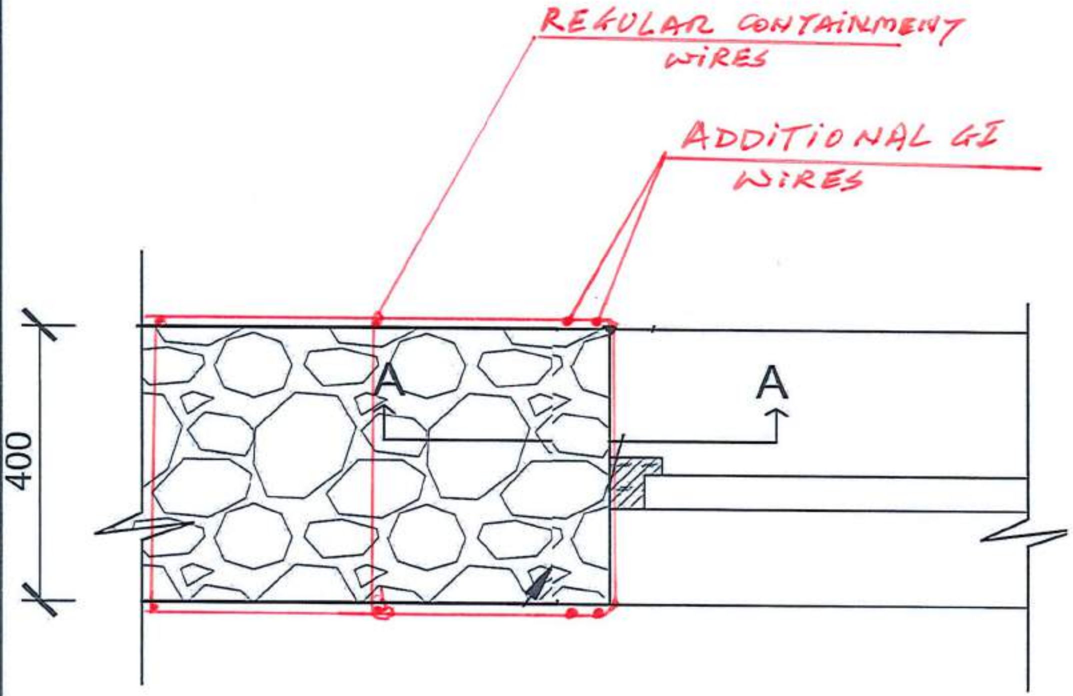
T- Junction Splint S2

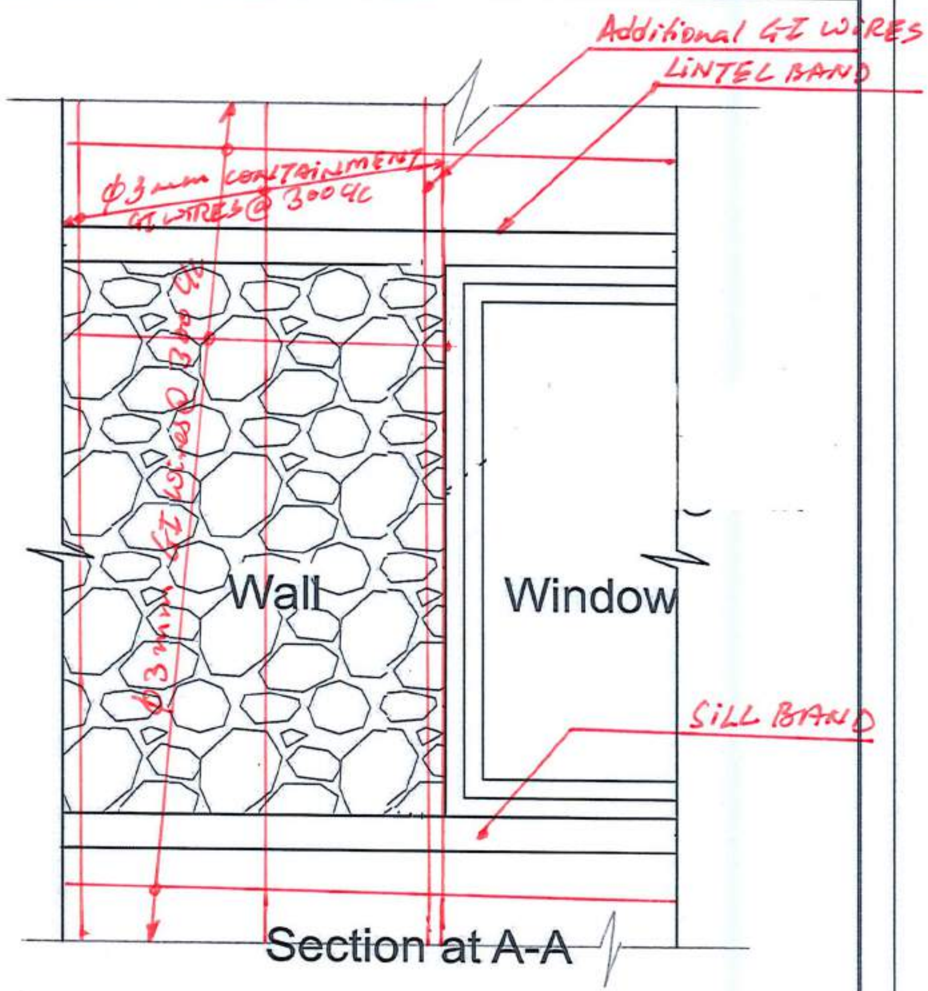
- Wires shown for splints are representative only

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale:	Date:	Sheet No.:
	Drawing Title:T-Junction Splint Detail	Design By:		ST-06

Type 2: Block stone masonry with Gabion mesh/Geogrid bands and wire containment

ONE STOREY

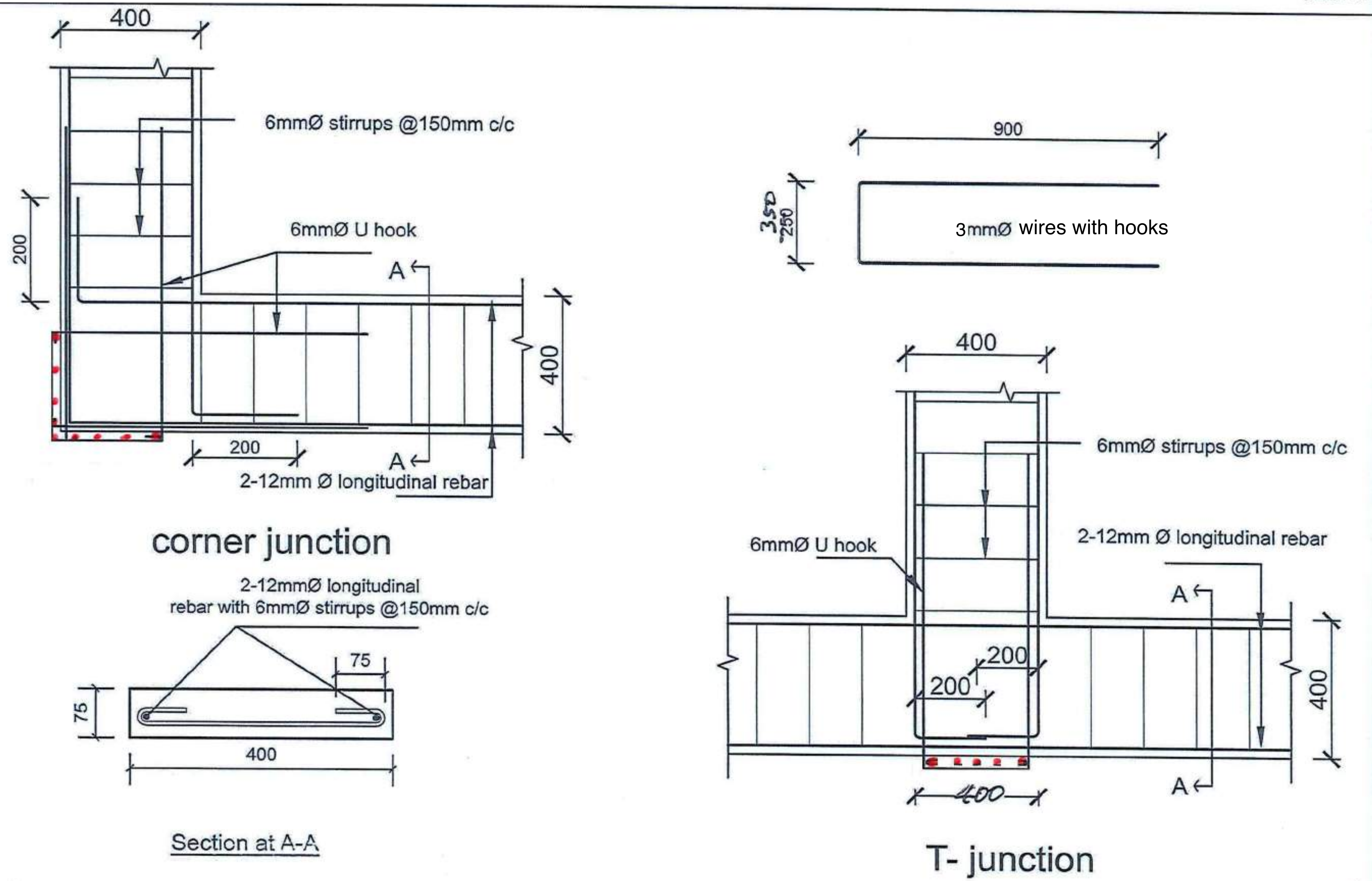




- Wires shown for splints are representative only

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale:	Date:	Sheet No.:
	Drawing Title: Jamb Detail	Design By:		ST-07

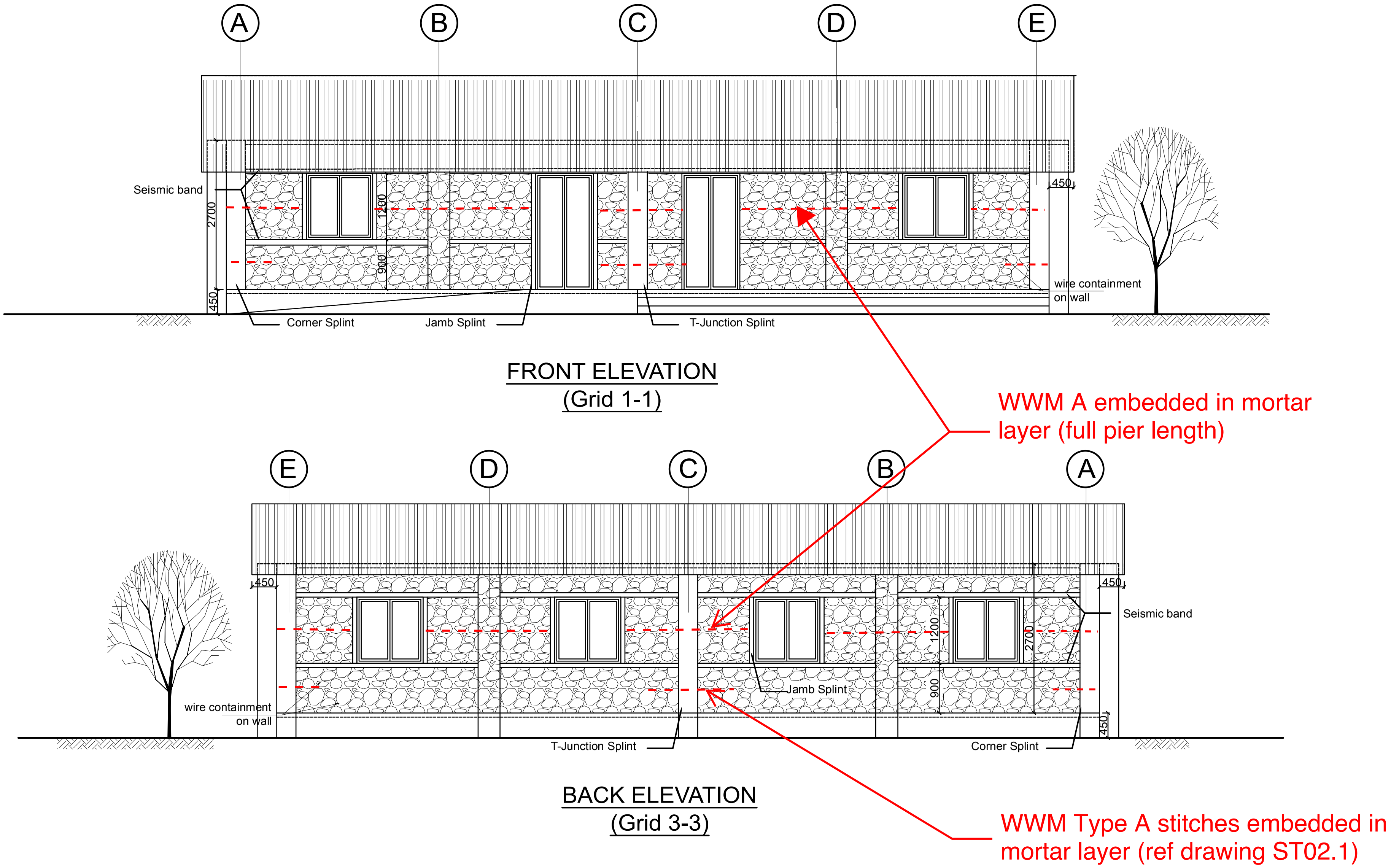
Type 2: Block stone masonry with Gabion mesh/Geogrid bands and wire containment ONE STOREY



Containment wires not shown for clarity

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale:	Date:	Sheet No.:
	Drawing Title:Plinth	Design By:		ST-08

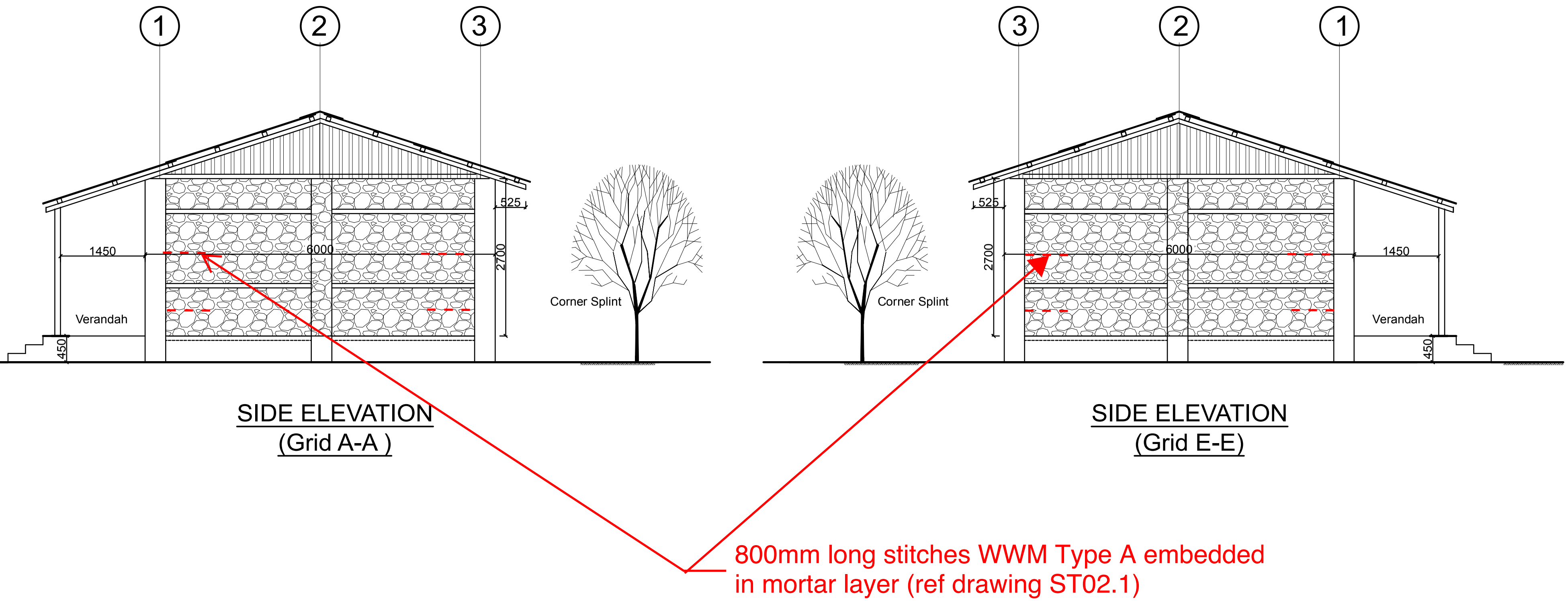
Type 2: Block stone masonry with Gabion mesh/Geogrid bands and wire containment — **ONE STOREY**



Central Level Project Implementation Unit **Ministry Of Education**	**Type: School Building Type Design for Remote Areas**	**Scale: 1:100**	**Date:2017-04-28**	Sheet No.:
	Drawing Title: Stitches	**Design By:**		AR-03

Type 2: Block stone masonry with Gabion mesh/Geogrid bands and wire containment

ONE STOREY



SIDE ELEVATION
(Grid A-A)

SIDE ELEVATION
(Grid E-E)

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale:	Date:	Sheet No.:
	Drawing Title:Elevations	Design By:		AR-04

Appendix A3 – Preliminary Design Drawings for Prototype (Type Design 3)

TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY

Material Specification

Masonry

Brick dimensions: 250x120x55mm
Mortar thickness: 10mm
Brick strength: > 4MPa (cement established, 5-8% of cement)
Mortar strength: 1-2MPA (cement established, 5-8% of cement, add 10% sand)
Wall thickness: 380mm (irrespective of whatever is noted in drawings)
Curing:
- Brick: No curing for a first couple of days (2-3 days), then light curing (could be covered with wet sacks)
- masonry: two weeks (could be covered with wet sacks)

Structural Concrete

Concrete compressive strength : 20MPa at 28 days
Concrete cover: 25mm
Concrete production should meet relevant standards

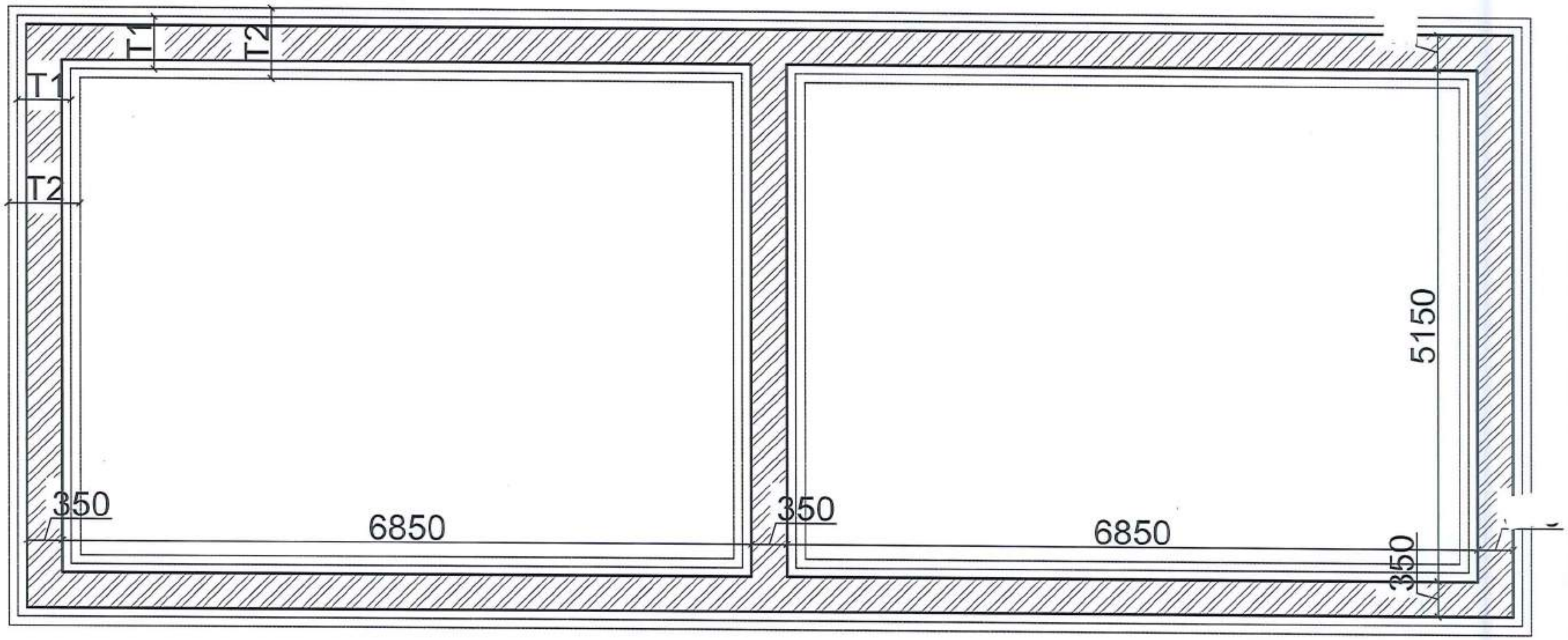
Reinforcing steel

Steel grade: 500MPa
Welded wire mesh diameter: 4mm @ 100x100grids
Reinforcing bars shall be bent cold
Minimum bend diameter for bending bars: 4xbar diameter

DEVELOPED DESIGN FOR DISCUSSION, FURTHER DEVELOPMENT AND FOR MODELLING

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:10	Date:2017-04-28	Sheet No.:
	Drawing Title: General Notes	Design By:		ST-0

TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS — ONE STOREY

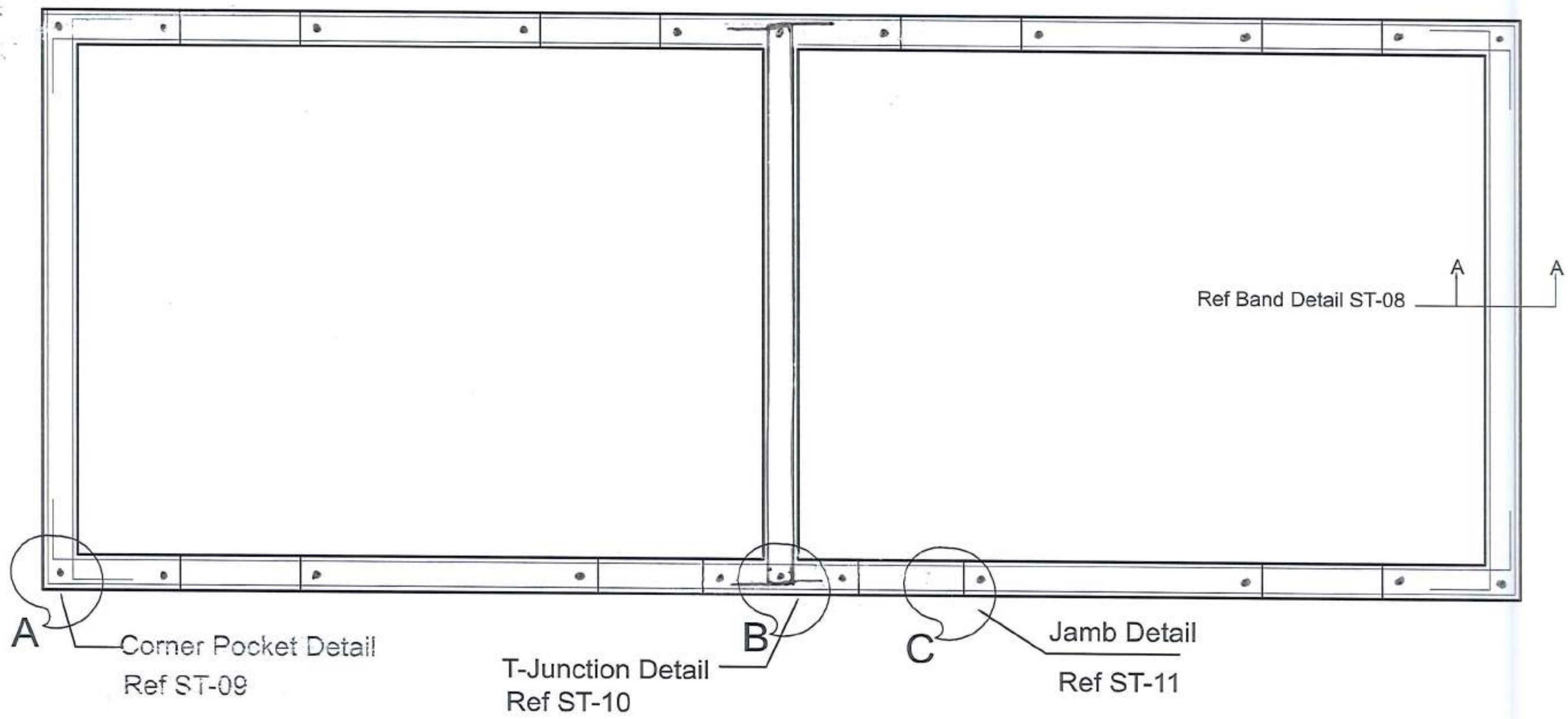


Trench Plan

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:60	Date:2017-04-28	Sheet No.:
	Drawing Title: Trench detail	Design By:		ST-01

TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS

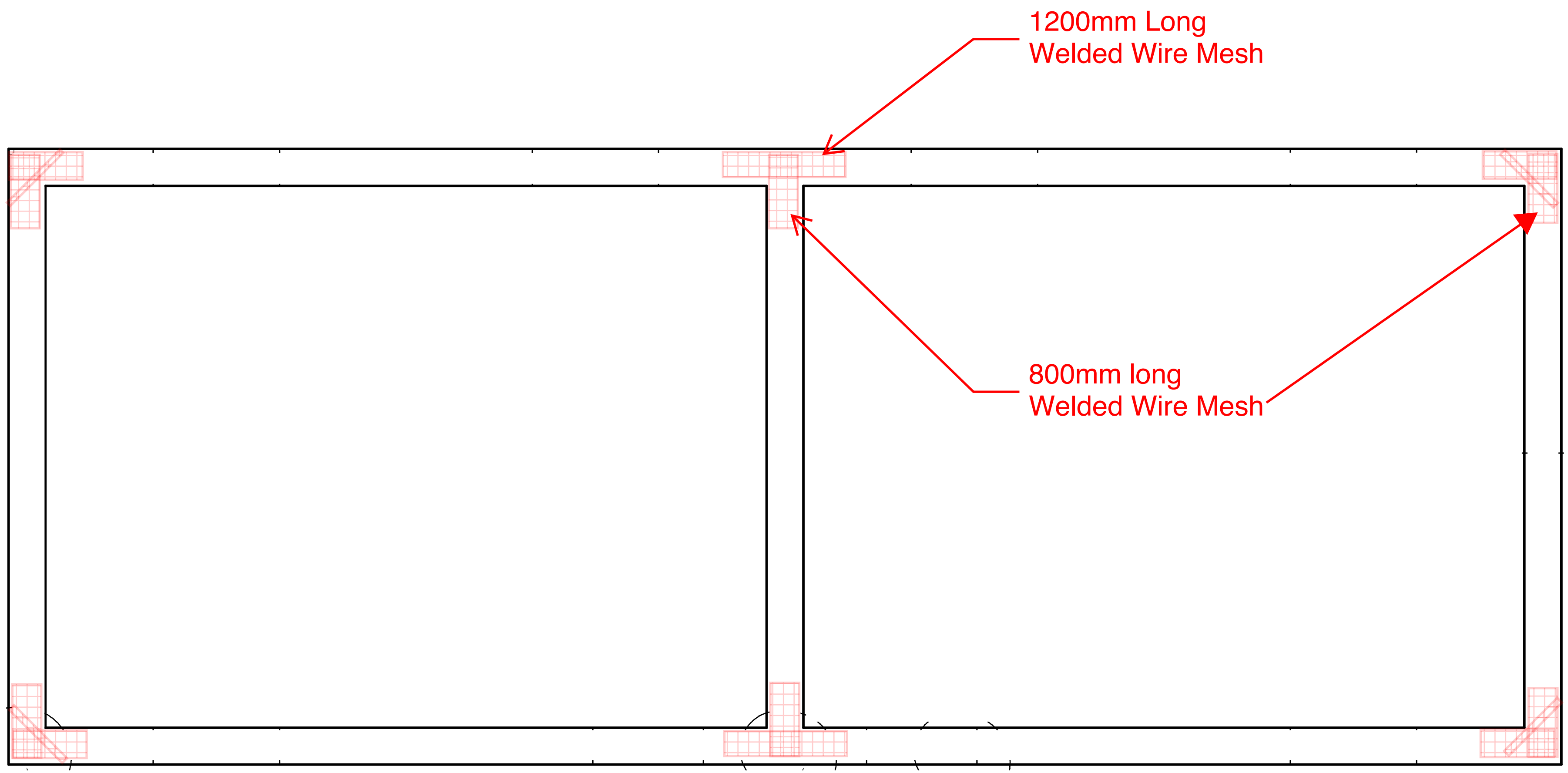
ONE STOREY



Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:10	Date:2017-04-28	Sheet No.:
	Drawing Title: Plan with bands and vertical bar	Design By:		ST-02

TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY

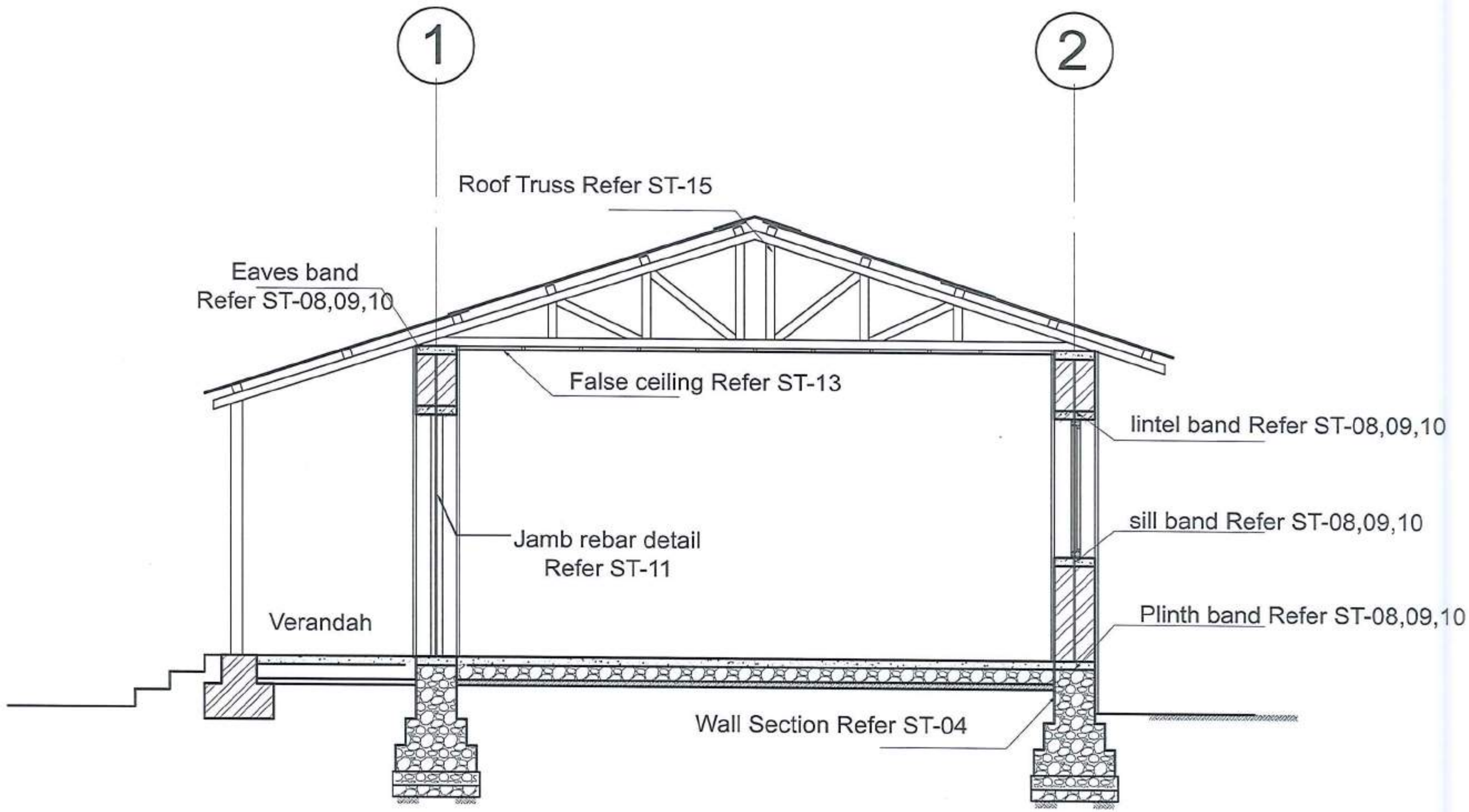


A

- Welded Wire Mesh (WWM) placed between DPC and Sill Level, and Sill and Lintel Level, Ref Ar03 and Ar04
- WWM embedded in the mortar layer

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:10	Date:2017-04-28	Sheet No.:
	Drawing Title: Stitch deatils	Design By:		ST-02.1

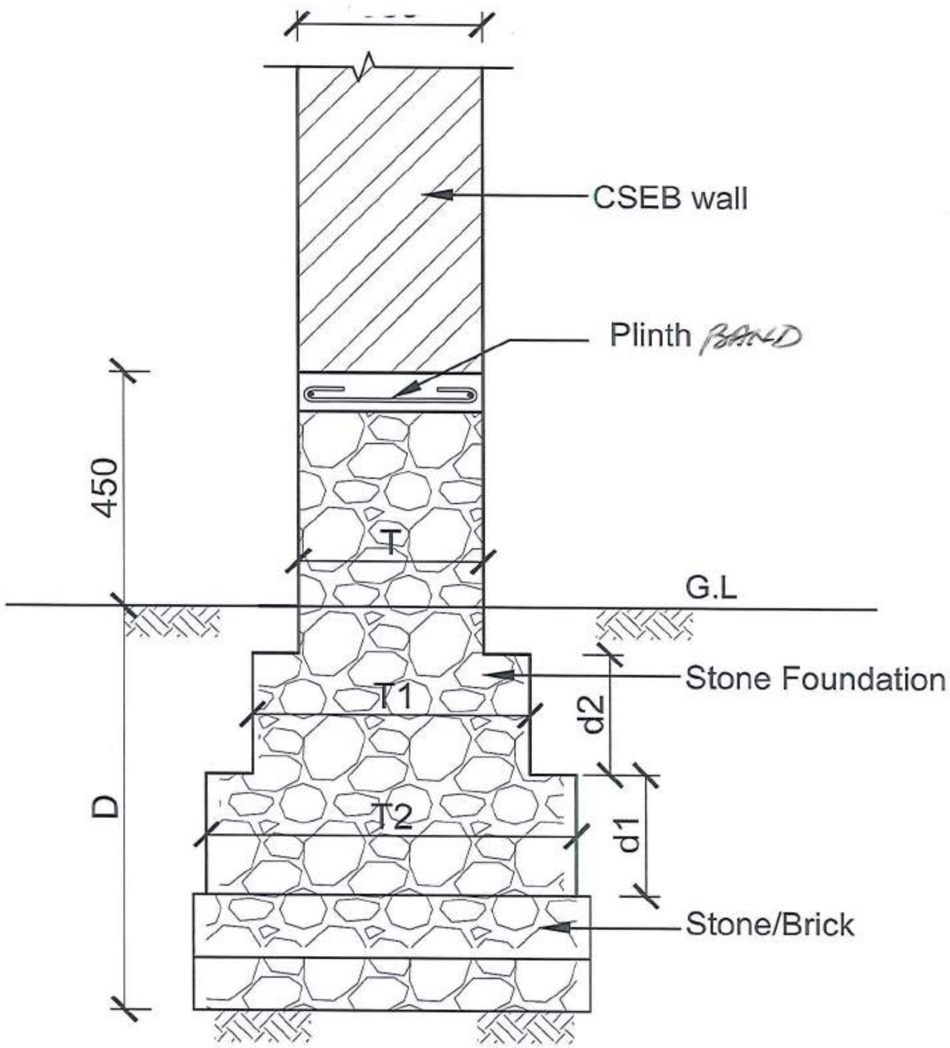
TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS | ONE STOREY



Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:50	Date:2017-04-28	Sheet No.:
	Drawing Title: Structural section	Design By:		ST-03

TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY

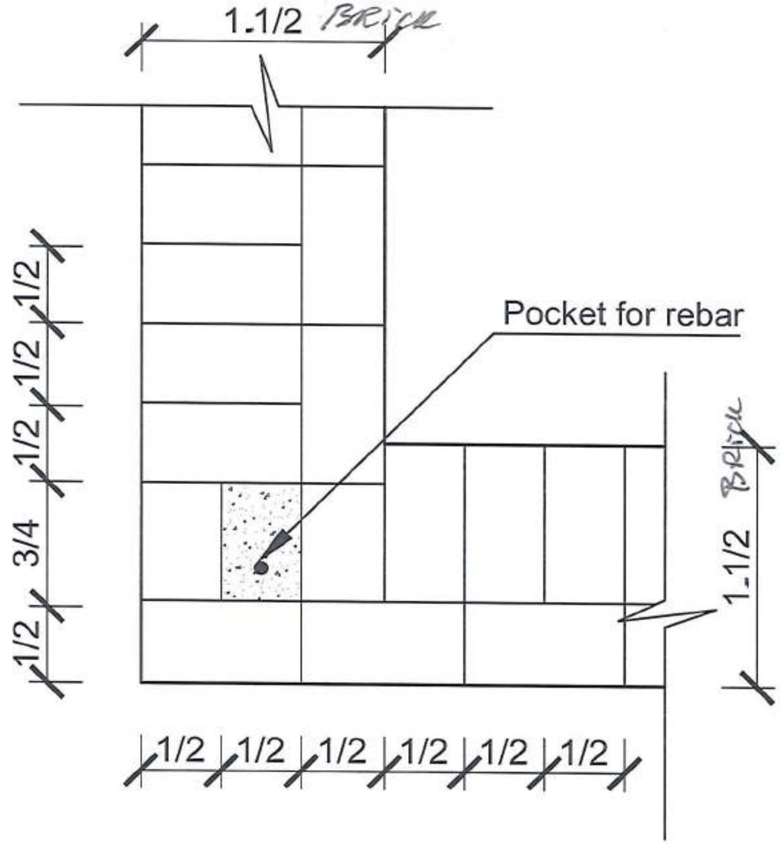


Wall Section (Foundation)

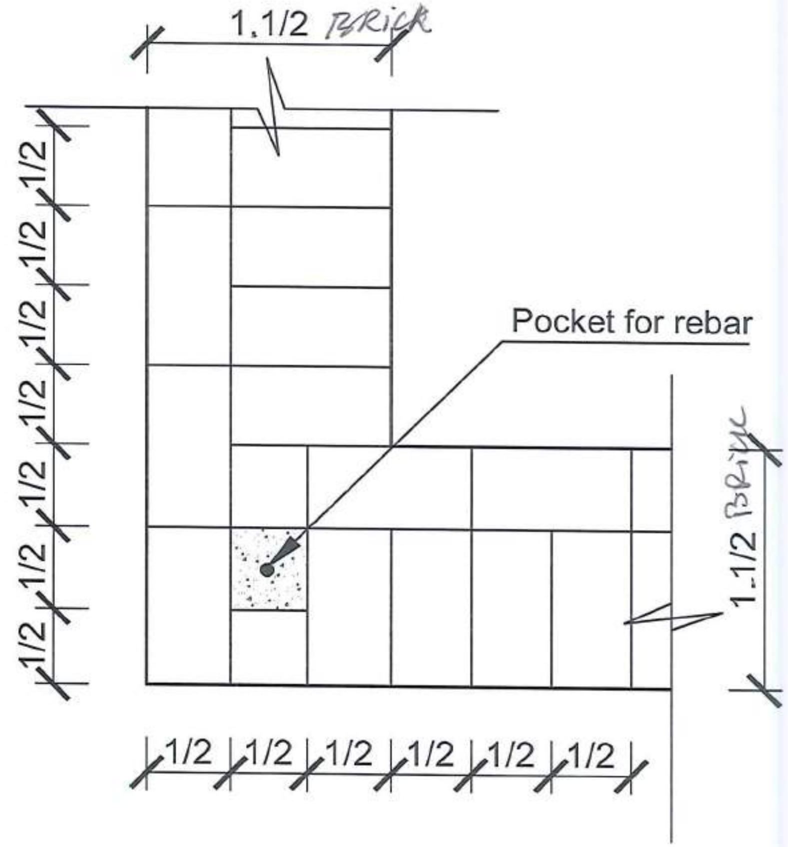
Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:10	Date:2017-04-28	Sheet No.:
	Drawing Title: Pocket Detail at A (Corner)	Design By:		ST-04

TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY



First Layer course
(Corner Junction)

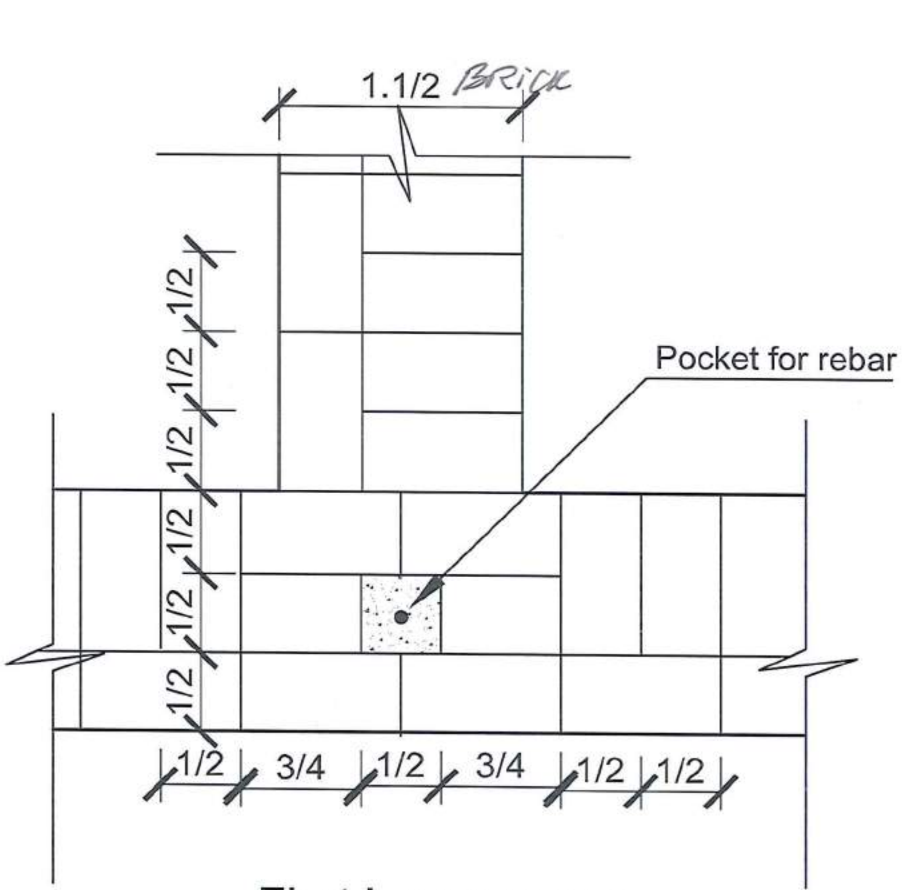


Second Layer course
(Corner Junction)

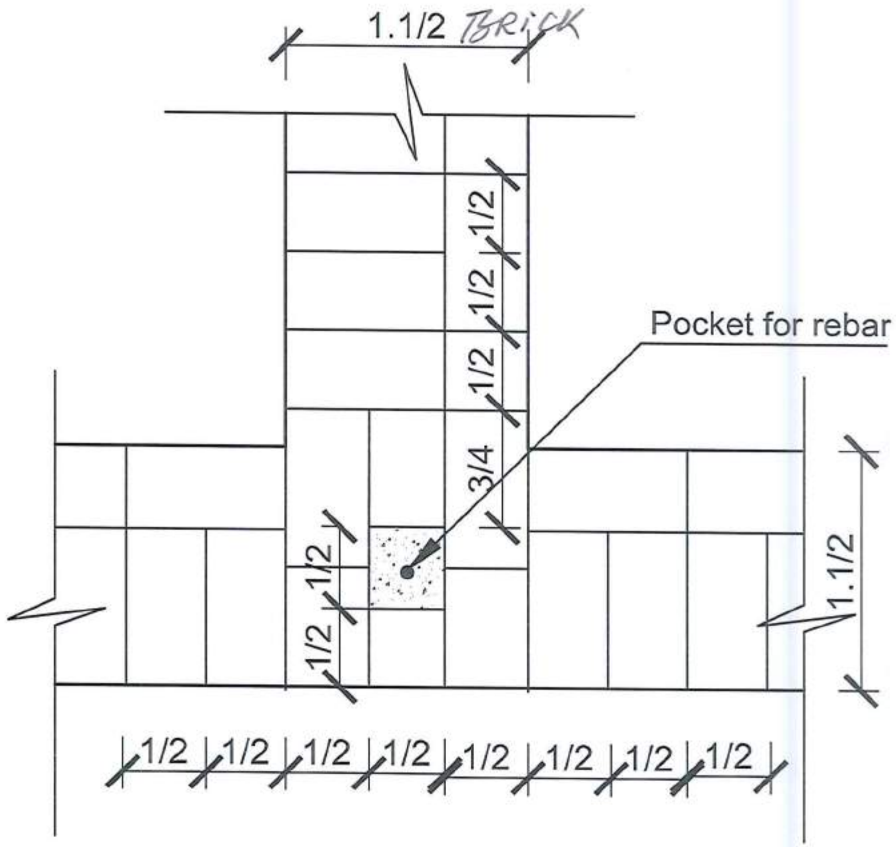
Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:10	Date:2017-04-28	Sheet No.:
	Drawing Title: Pocket Detail at A (Corner Junction)	Design By:		ST-05

TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY



First Layer course
(T-junction)

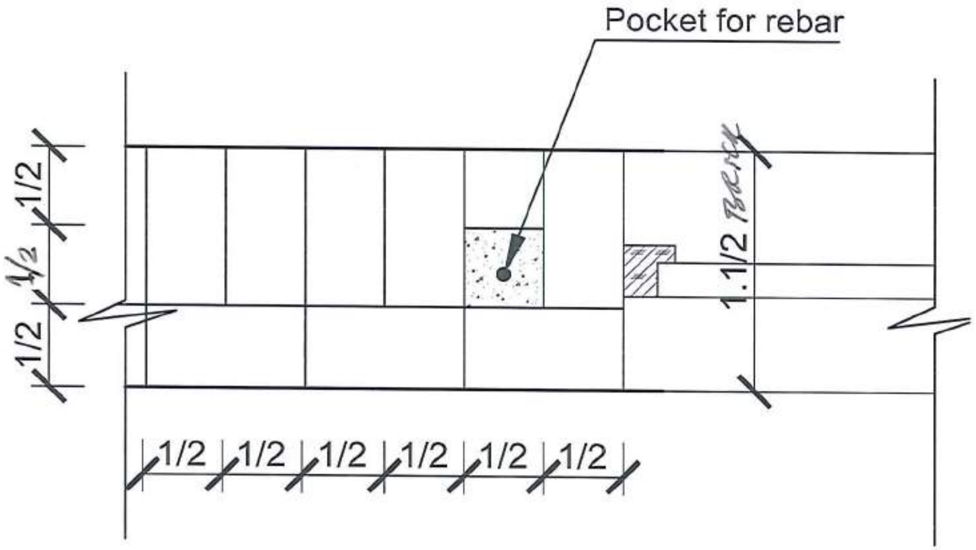


Second Layer course
(T-junction)

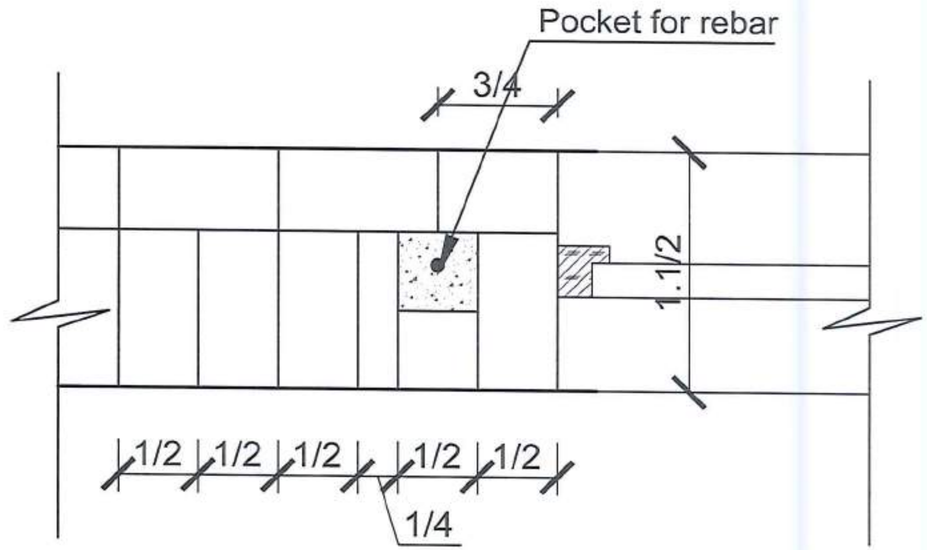
Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:10	Date:2017-04-28	Sheet No.:
	Drawing Title: Pocket Detail at B (T-Junction)	Design By:		ST-06

TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY



First Layer course
(Door/Window Jamb)

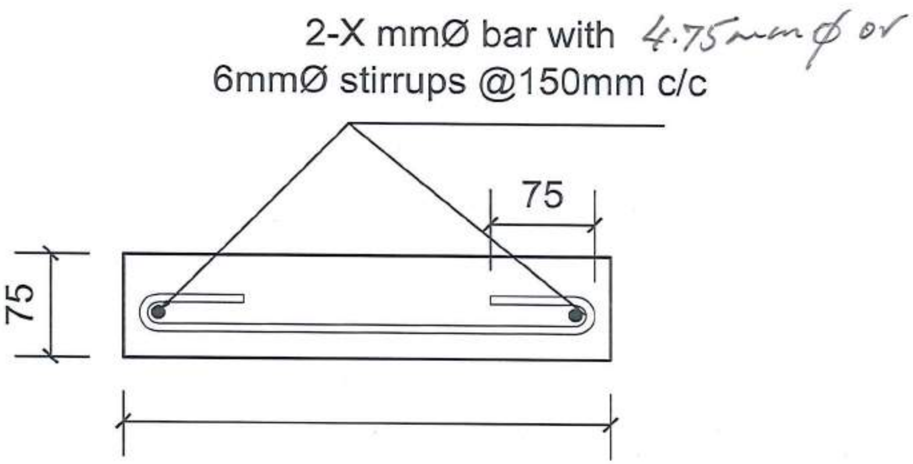


Second Layer course
(Door/Window Jamb)

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:10	Date:2017-04-28	Sheet No.:
	Drawing Title: Pocket Detail at C (Jamb Opening)	Design By:		ST-07

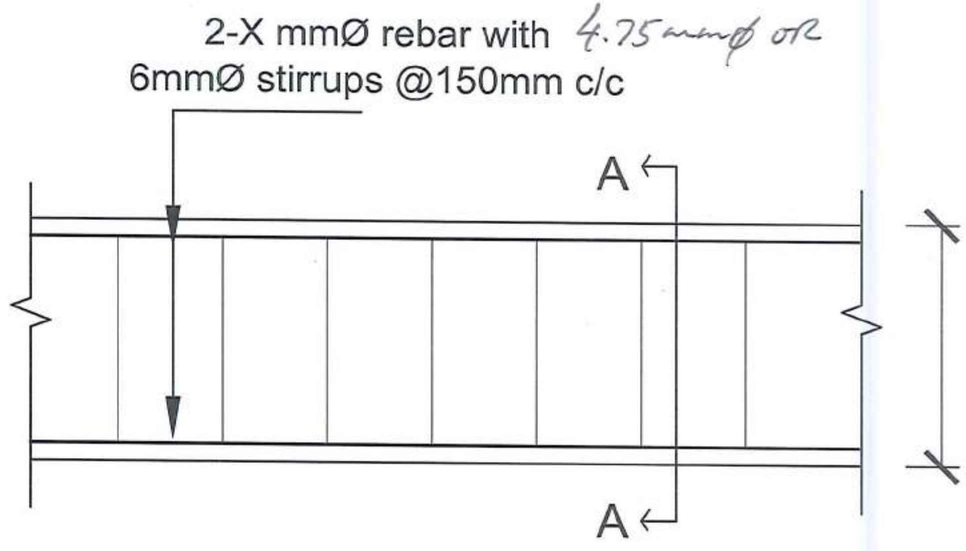
TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY



Section at A-A
Band Detail

Rebar size in bands	
Band level	Rebar Diameter (X)
Plinth band	12mm
Sill band	12mm
Lintel band	16mm
Eaves	12mm



Typical band plan

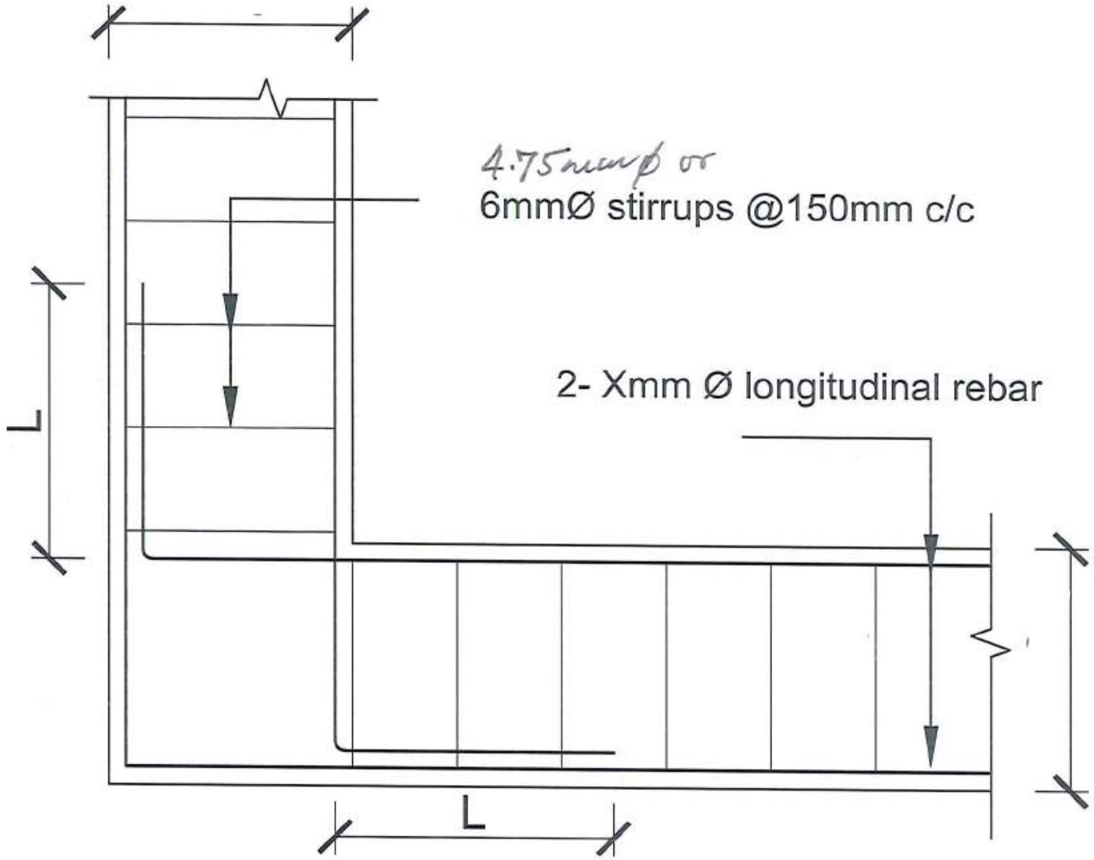
Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:10	Date:2017-04-28
	Drawing Title: Band Details	Design By:	Sheet No.: ST-08

TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY

Lap length	
Rebar Diameter	L
12mm	200mm
16mm	400mm

Rebar size in bands	
Band level	Rebar Diameter (X)
Plinth band	12mm
Sill band	12mm
Lintel band	16mm
Eaves	12mm



Band detail at corner junction

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:10	Date:2017-04-28	Sheet No.:
	Drawing Title: Band at corner junction detail	Design By:		ST-09

TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS

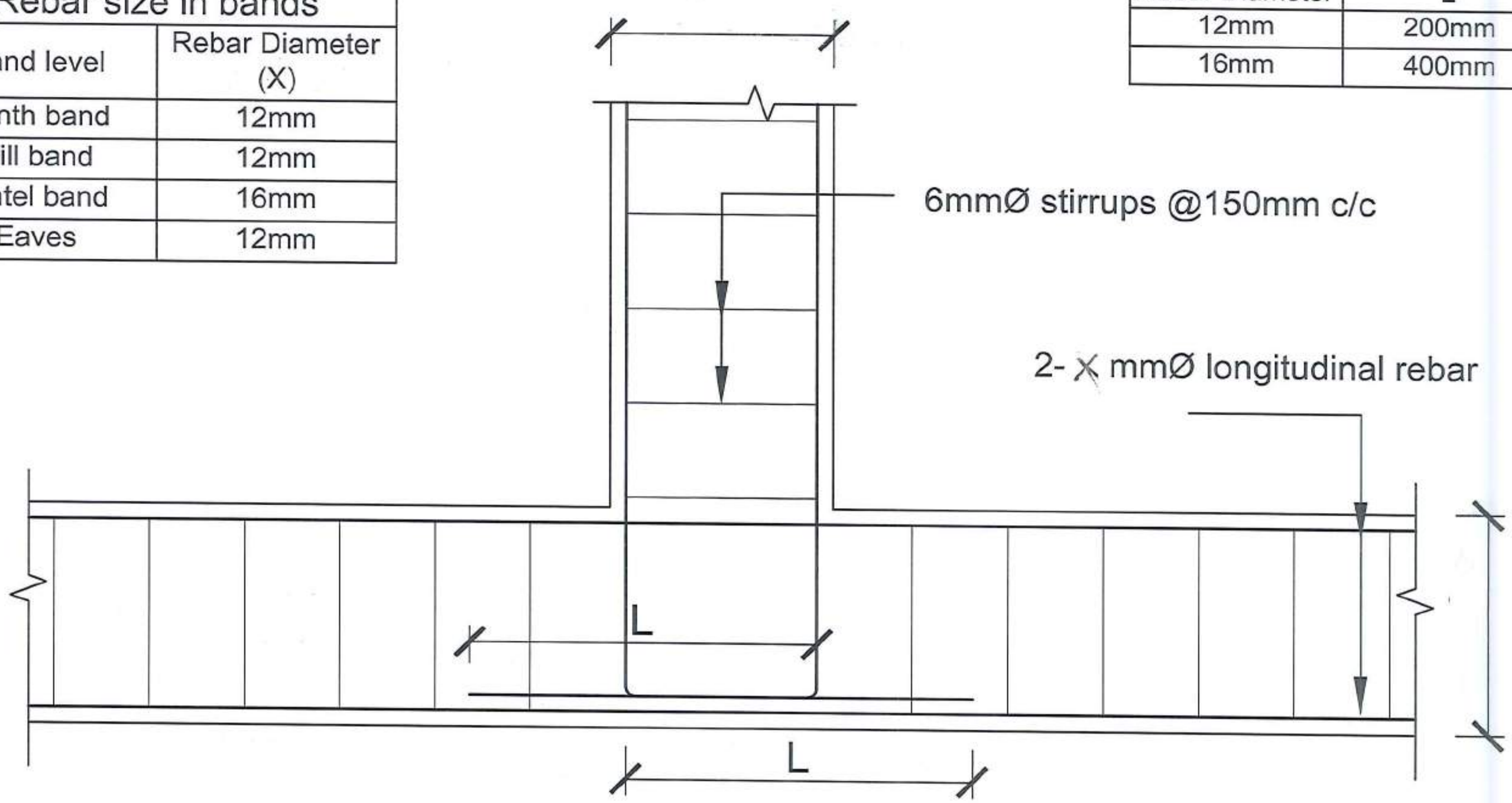
ONE STOREY

Rebar size in bands

Band level	Rebar Diameter (X)
Plinth band	12mm
Sill band	12mm
Lintel band	16mm
Eaves	12mm

Lap length

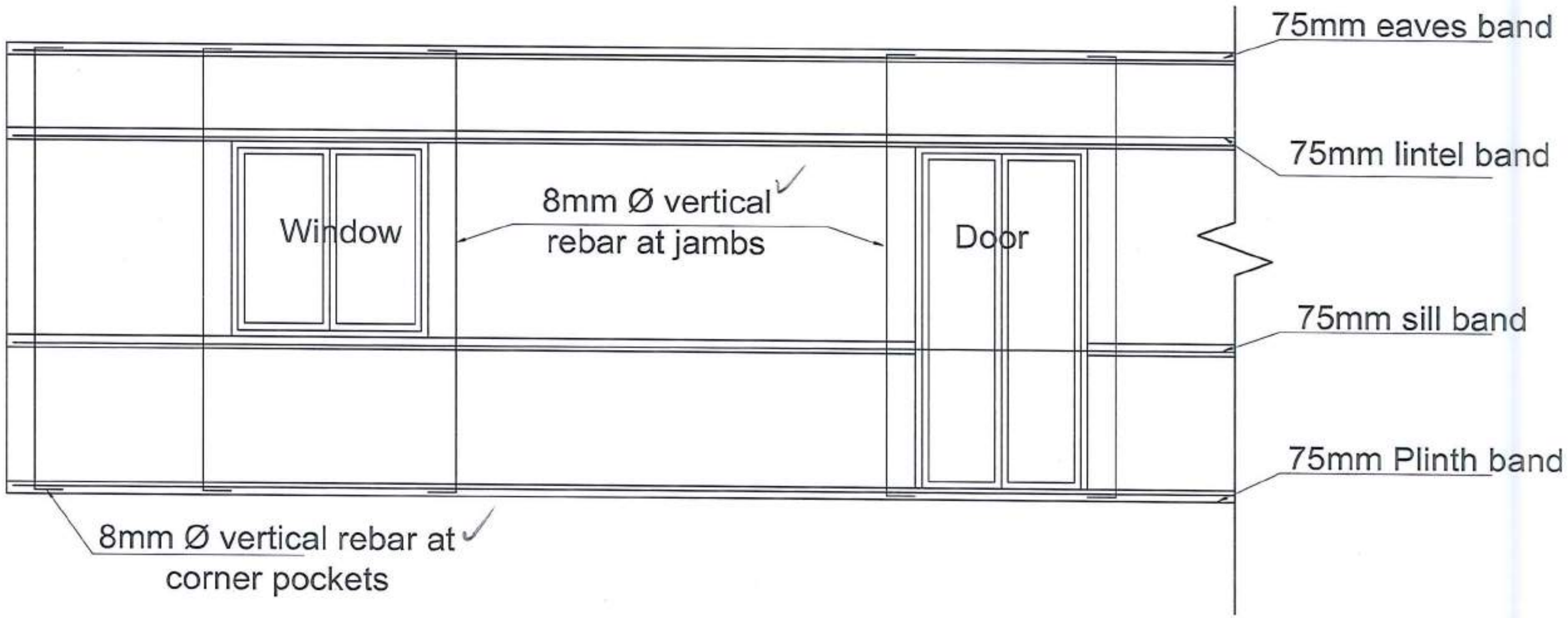
Rebar Diameter	L
12mm	200mm
16mm	400mm



Band detail at T- junction

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:10	Date:2017-04-28	Sheet No.:
	Drawing Title: Roof Band	Design By:		ST-10

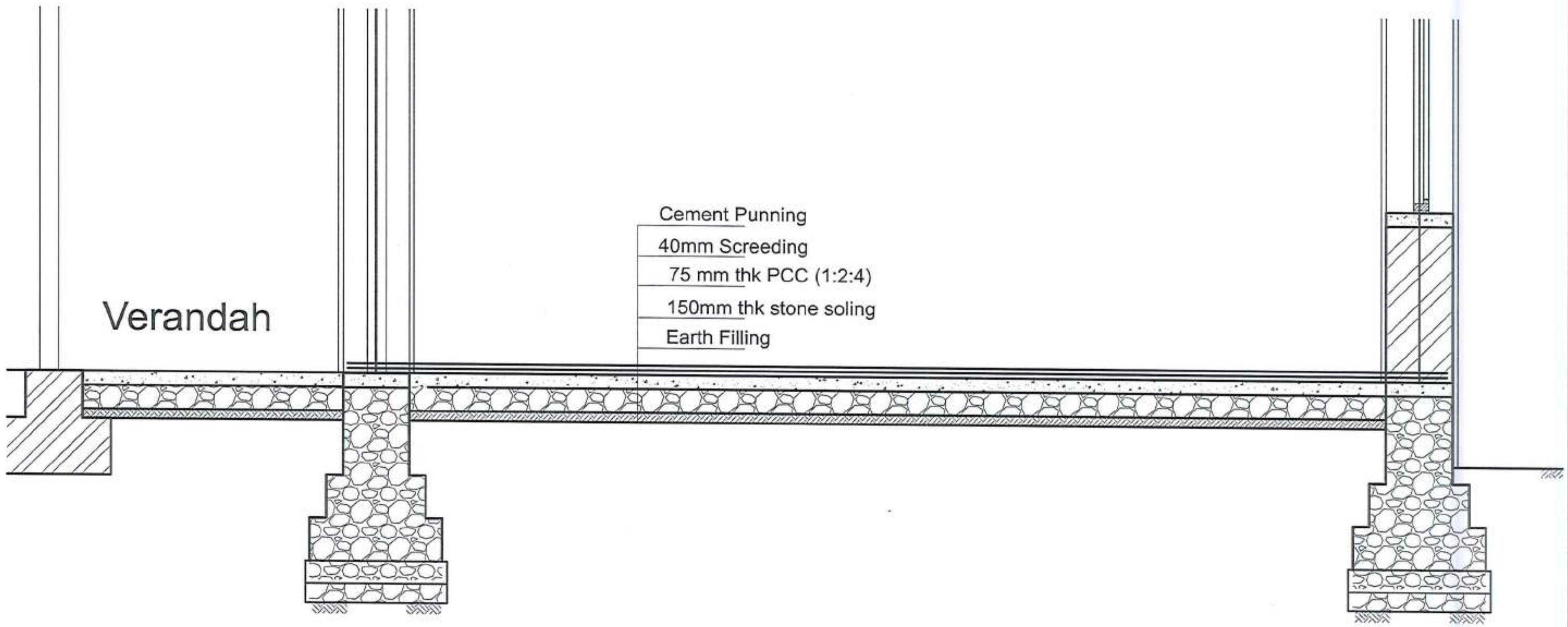
TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS | ONE STOREY



Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:40	Date:2017-04-28	Sheet No.:
	Drawing Title: Vertical bar anchor details	Design By:		ST-11

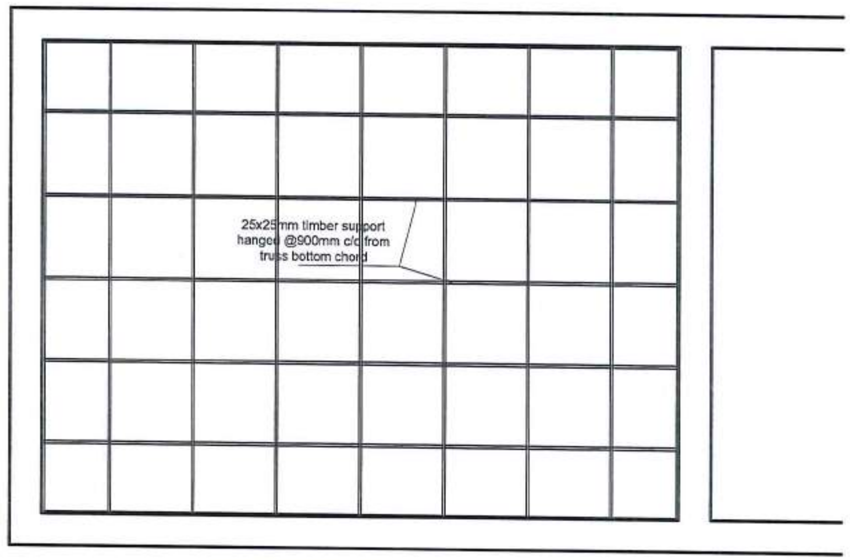
TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY

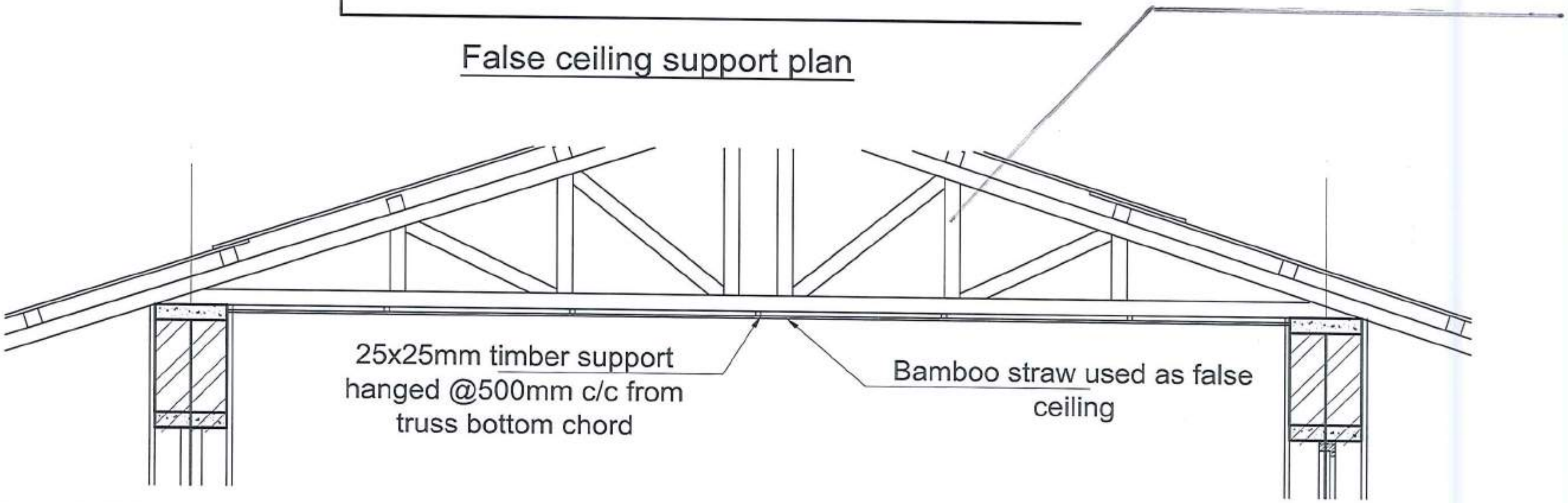


Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:30	Date:2017-04-28	Sheet No.:
	Drawing Title: Flooring details	Design By:		ST-12

TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS | ONE STOREY



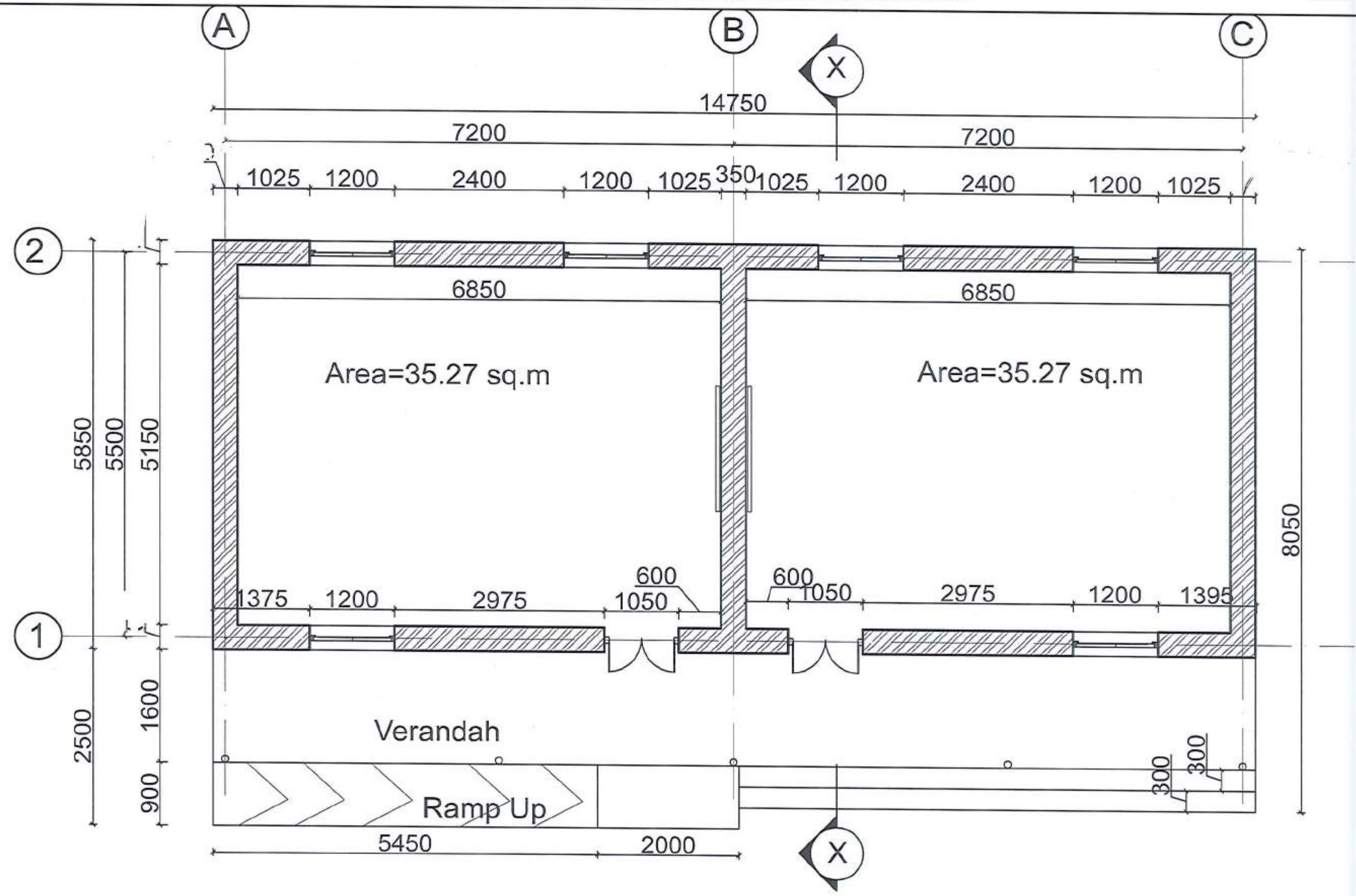
False ceiling support plan



Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:10	Date:2017-04-28	Sheet No.:
	Drawing Title: False ceiling details	Design By:		ST-13

TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS

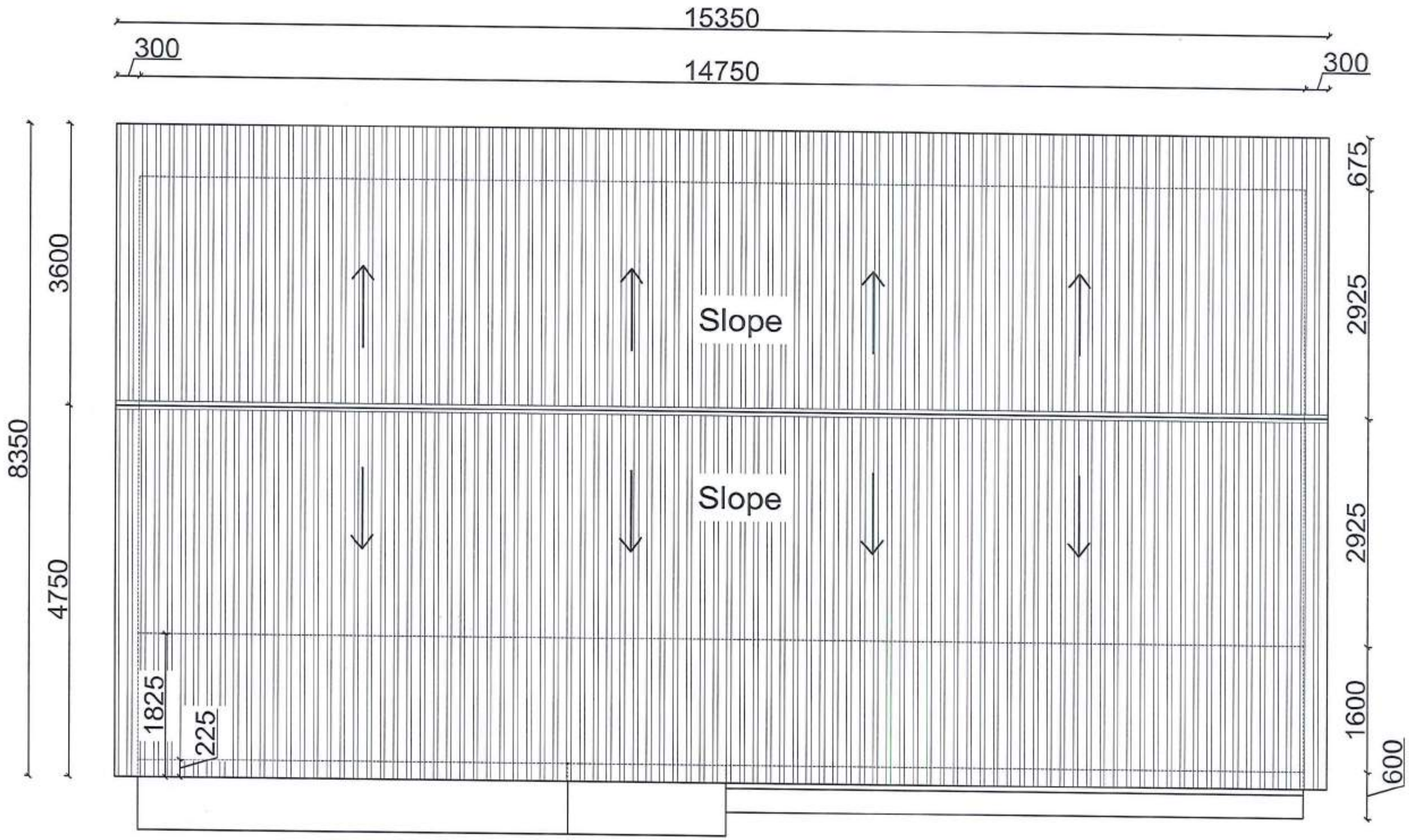
ONE STOREY



Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:75	Date:2017-04-28	Sheet No.:
	Drawing Title: Floor Plan	Design By:		AR-01

TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS

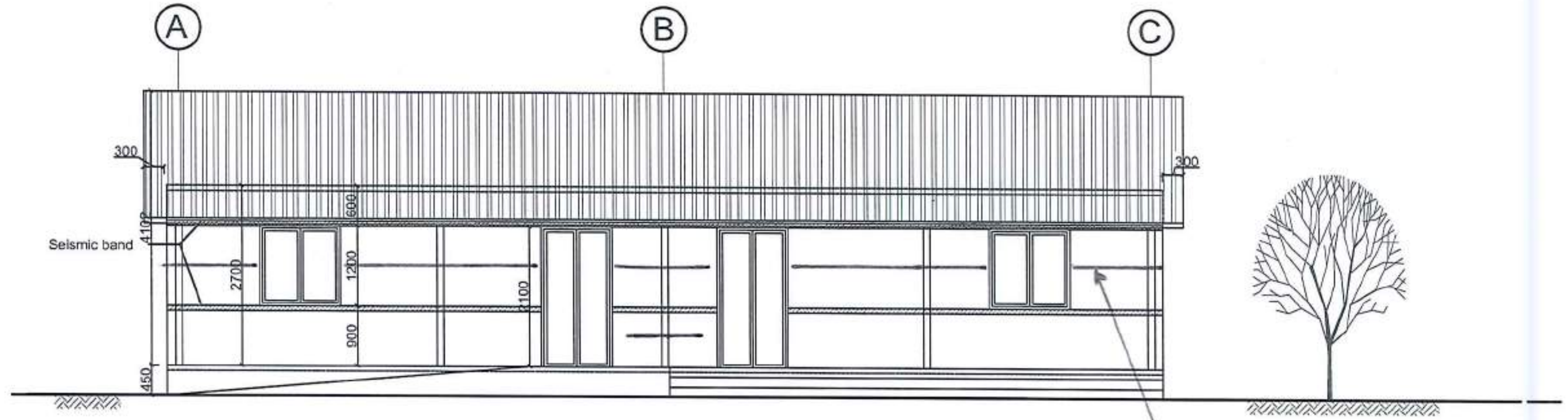
ONE STOREY



Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:75	Date:2017-04-28	Sheet No.:
	Drawing Title: Roof Plan	Design By:		AR-02

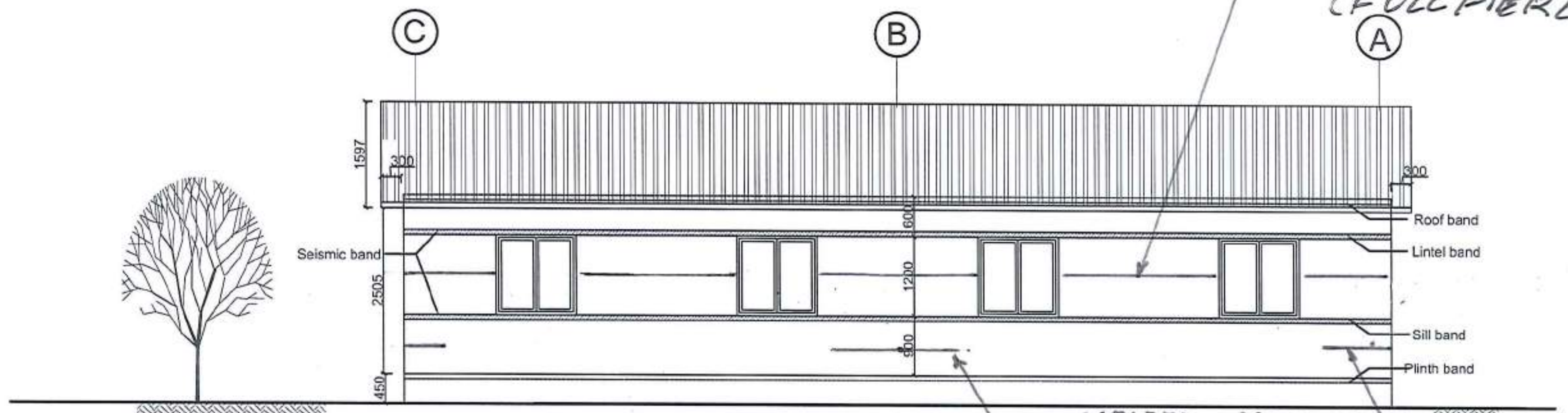
TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY



FRONT ELEVATION
(Grid 1-1)

WELDED WIRE MESH
EMBEDED IN MORTAR LAYER
(FULL PIER LENGTH)



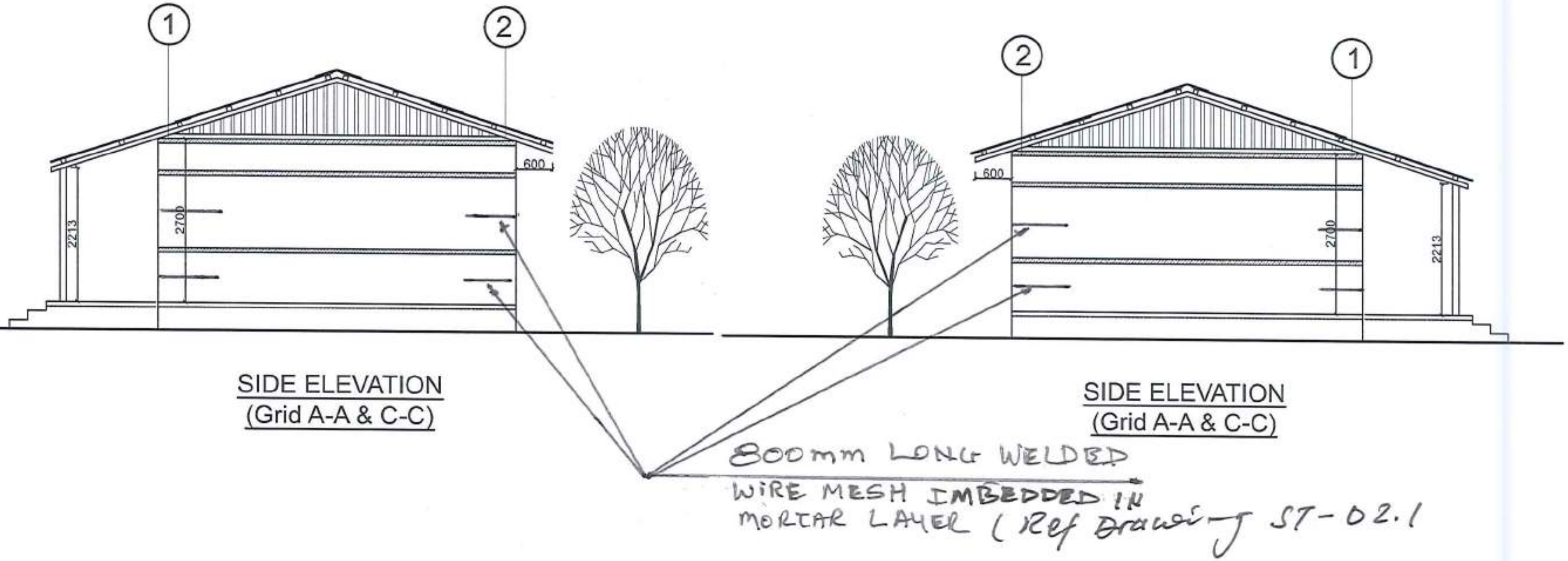
WELDED WIRE MESH
EMBEDED IN MORTAR LAYER
(REF DRAWING ST-02.1

BACK ELEVATION
(Grid 2-2)

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:100	Date:2017-04-28	Sheet No.:
	Drawing Title: Elevations	Design By:		AR-03

TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS

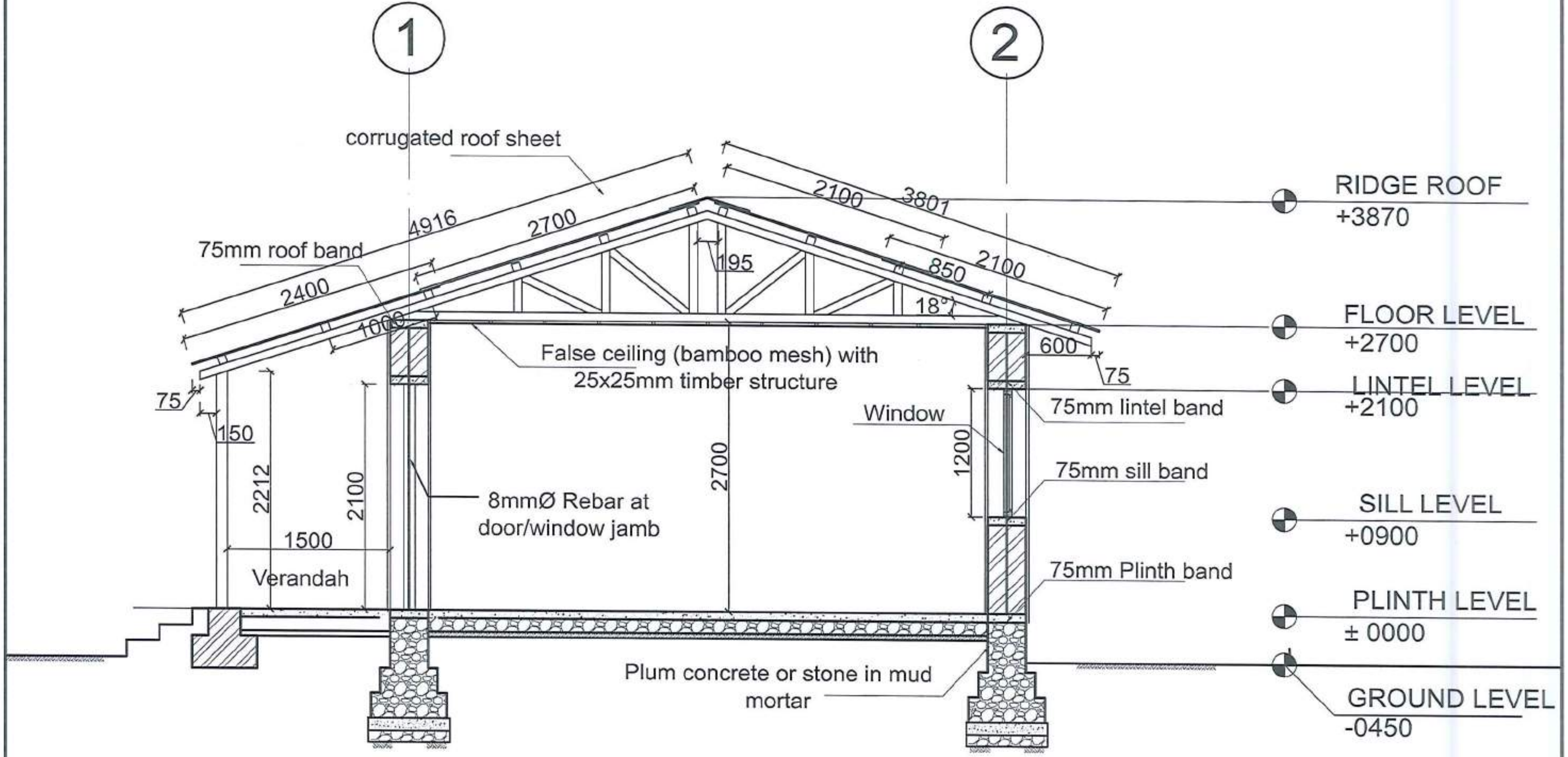
ONE STOREY



Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:100	Date:2017-04-28	Sheet No.:
	Drawing Title: Elevations	Design By:		AR-04

TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS

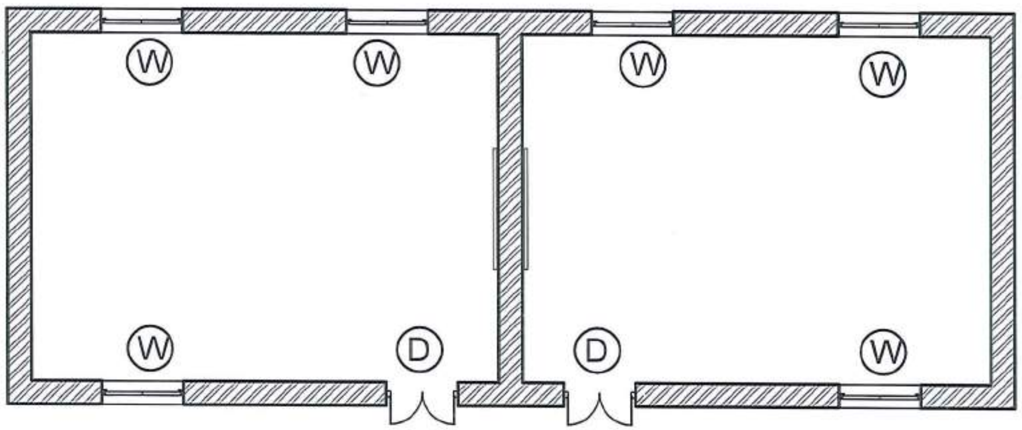
ONE STOREY



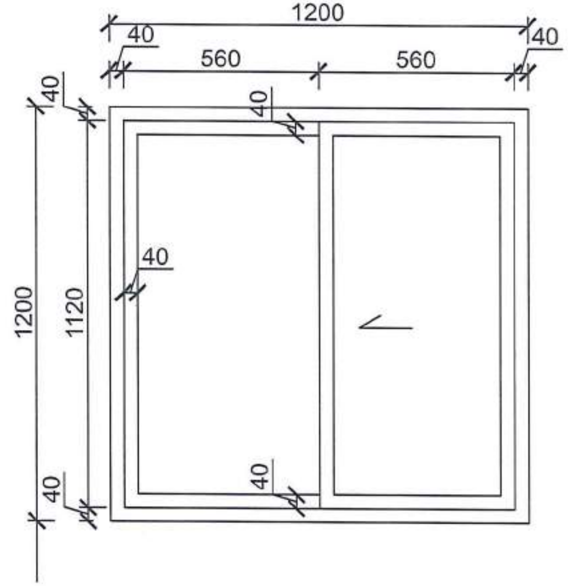
SECTION AT XX (T1)

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:50	Date:2017-04-28	Sheet No.:
	Drawing Title: Sections	Design By:		AR-05

TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS | ONE STOREY



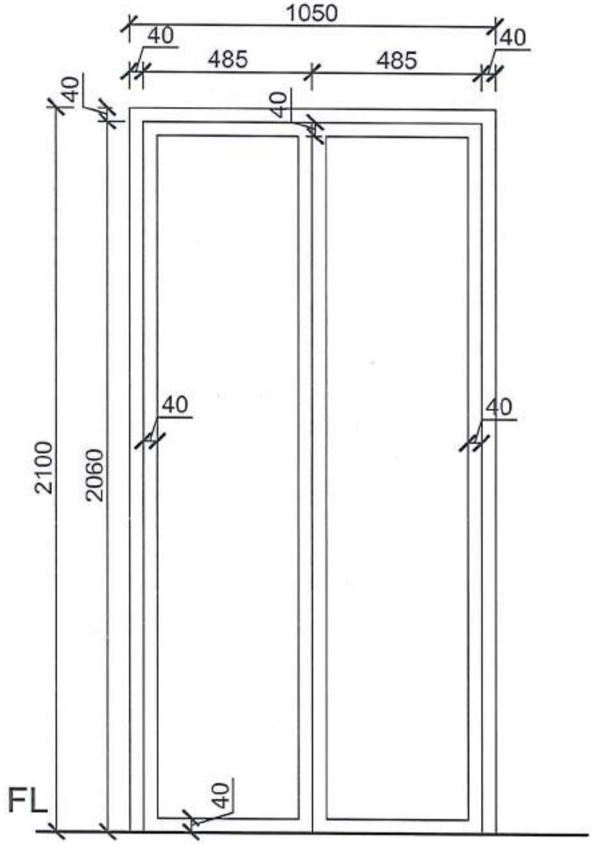
Door Window Schedule Plan



Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:50	Date:2017-04-28	Sheet No.:
	Drawing Title: Window Detail	Design By:		AR-06

TYPE DESIGN: CEMENT STABILIZED EARTH BRICK IN CEMENT STABILIZED MORTAR AND RCC BANDS

ONE STOREY



Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:50	Date:2017-04-28	Sheet No.:
	Drawing Title:Door Detail	Design By:		AR-07

Appendix A4 – Preliminary Design Drawings for Prototype

(Type Design 4)

Type 4: Block stone masonry with timber bands and wire containment ONE STOREY

Material Specification

Masonry

Stone dressing: semi-dressed
Stone dimension: no dimension <150mm
Mortar thickness: 10mm*
Mortar strength: 1-2MPA (cement established, 5-8% of cement, add 10% sand)*
Wall thickness: 400mm (irrespective of whatever is noted in drawings)
Curing:
- masonry: two weeks (could be covered with wet sacks)

Masonry compressive strength = 1.8MPa
Masonry tensile strength = 0MPa
Masonry Young's Modulus = 350MPa

Structural Concrete
Concrete compressive strength : 20MPa at 28 days
Concrete cover: 25mm
Concrete production should meet relevant standards

Reinforcing steel

Steel grade: 500MPa
WWM A: Welded wire mesh for stitches: 4mm both directions @ 100x100grids
WWM B: Welded wire mesh for containment: 3mm both directions @ 300x300grids
Reinforcing bars shall be bent cold
Minimum bend diameter for bending bars: 4xbar diameter

Plaster

Cement stablised soil plaster

SWG Wires

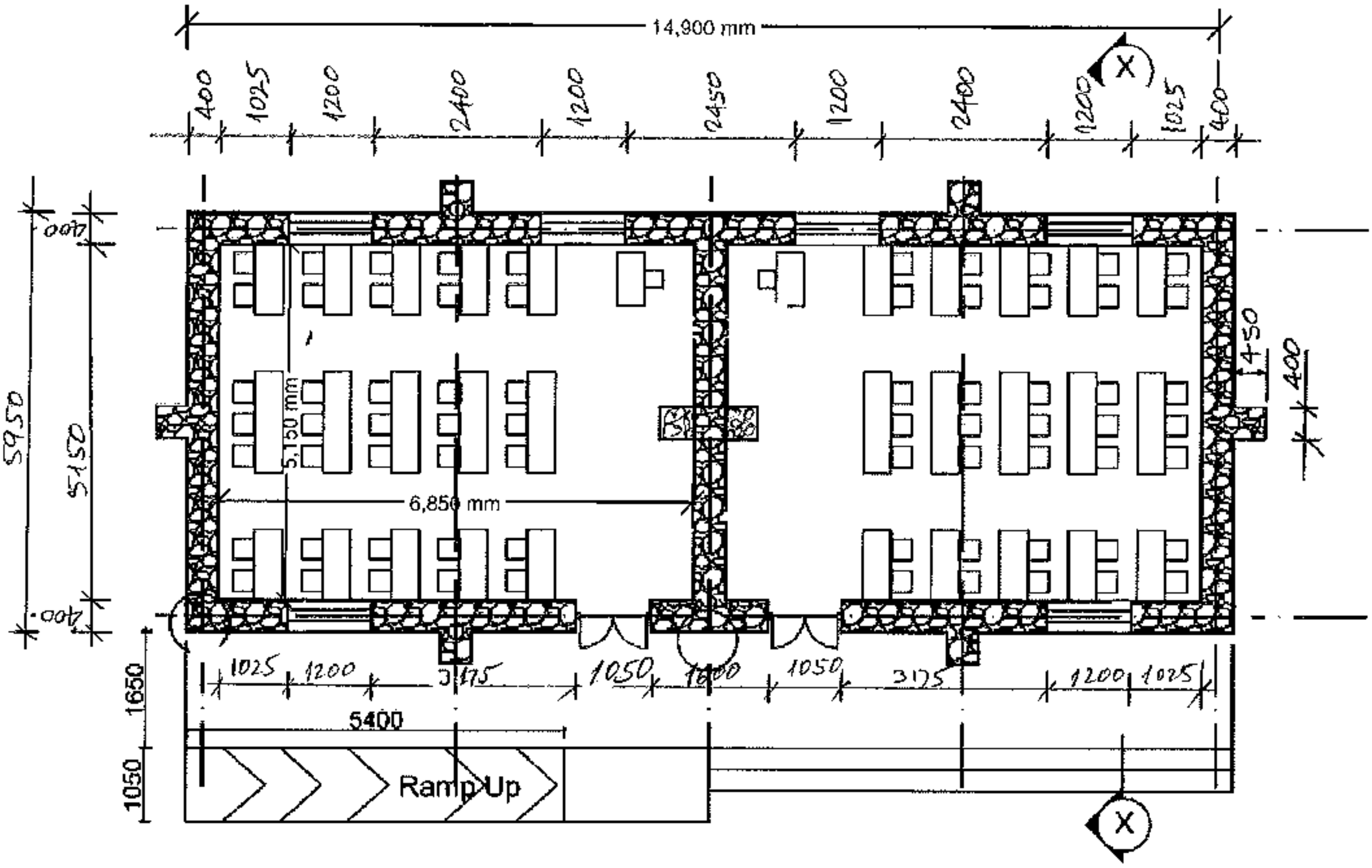
Yield strength: 380MPa

Timber (permissible strengths)
Bending strength: 8.9MPa
Tensile strength: 5.8MPa
Shear strength: 0.57MPa

Drawings shall not be scalled

DEVELOPED DESIGN FOR DISCUSSION, FURTHER DEVELOPMENT AND SCALLED MODELLING

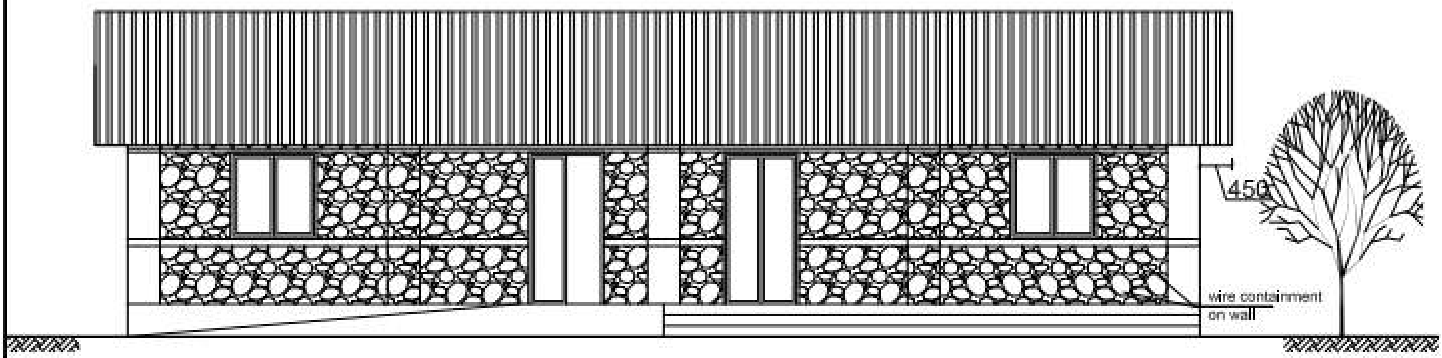
Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale:	Date: 09/11/2017	Sheet No.:
	Drawing Title: General Notes	Design By:		ST-0



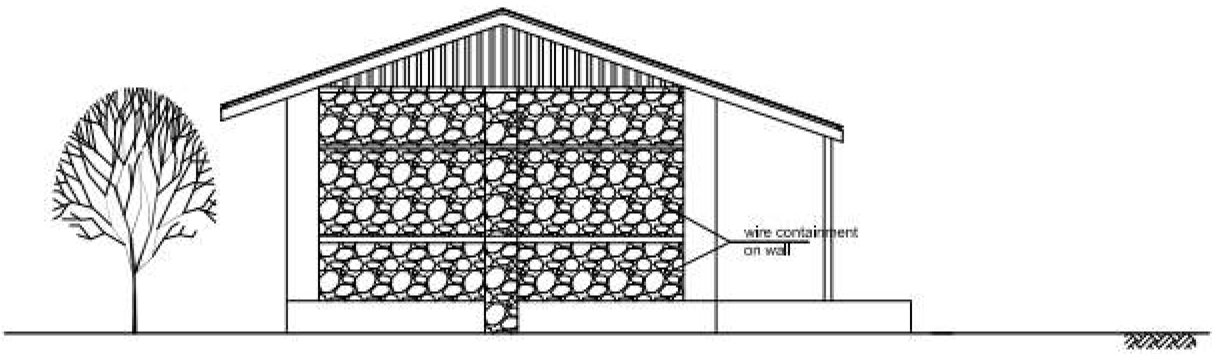
PLAN (2 rooms)

Note: The drawings are only for discussion not construction.

Type 4: Block stone masonry with timber bands and wire containment



FRONT ELEVATION

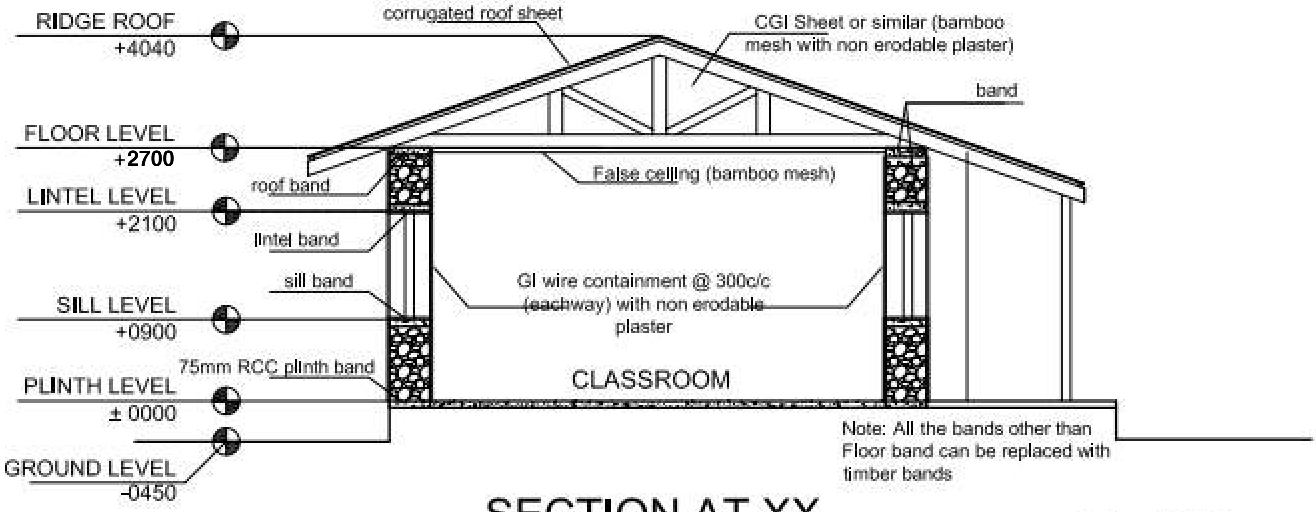


SIDE ELEVATION

Scale -1:2500

Note: The drawings are only for discussion not construction.

Type 4: Block stone masonry with timber bands and wire containment



SECTION AT XX

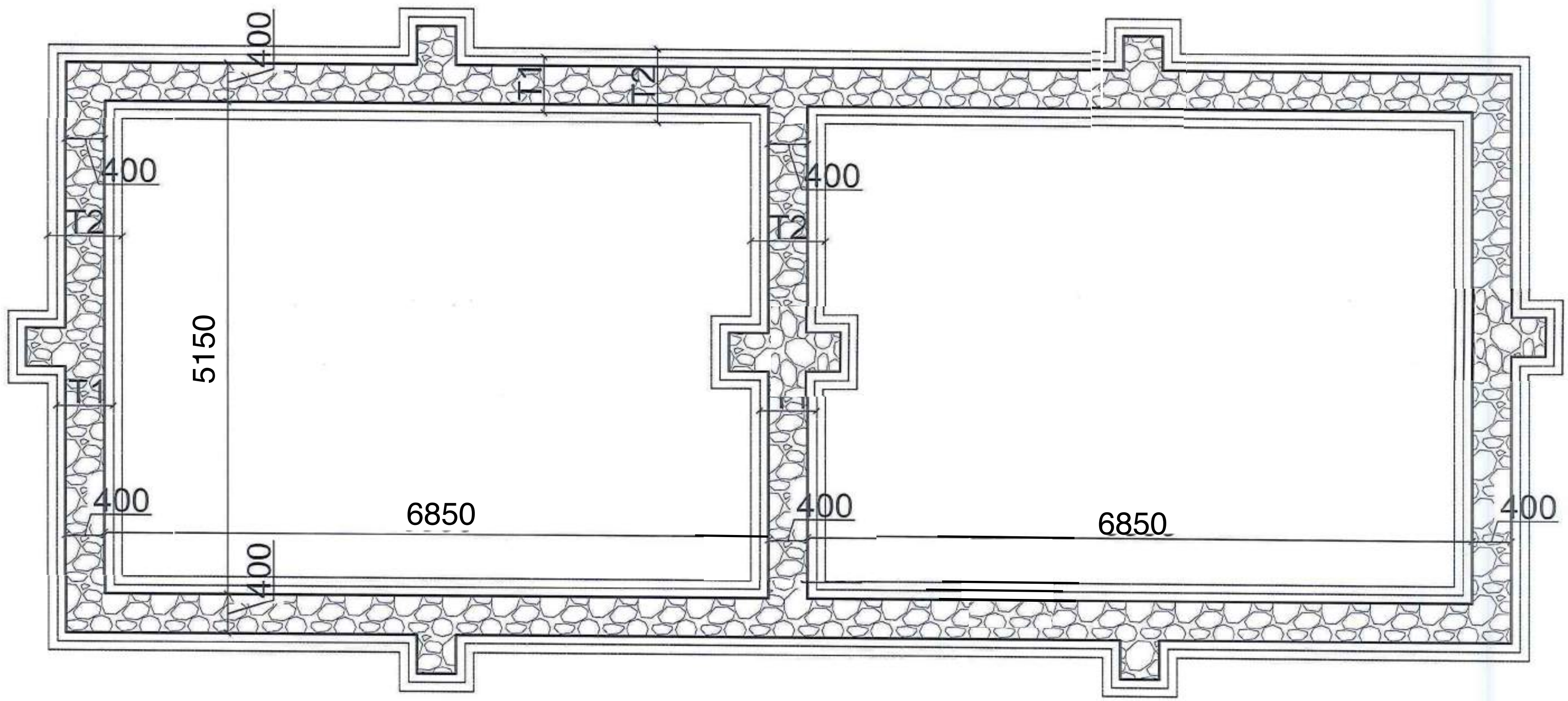
Scale -1:2000

Note: The drawings are only for discussion not construction.

Type 4: Block stone masonry with timber bands and wire containment

Type 4: Block stone masonry with timber bands and wire containment

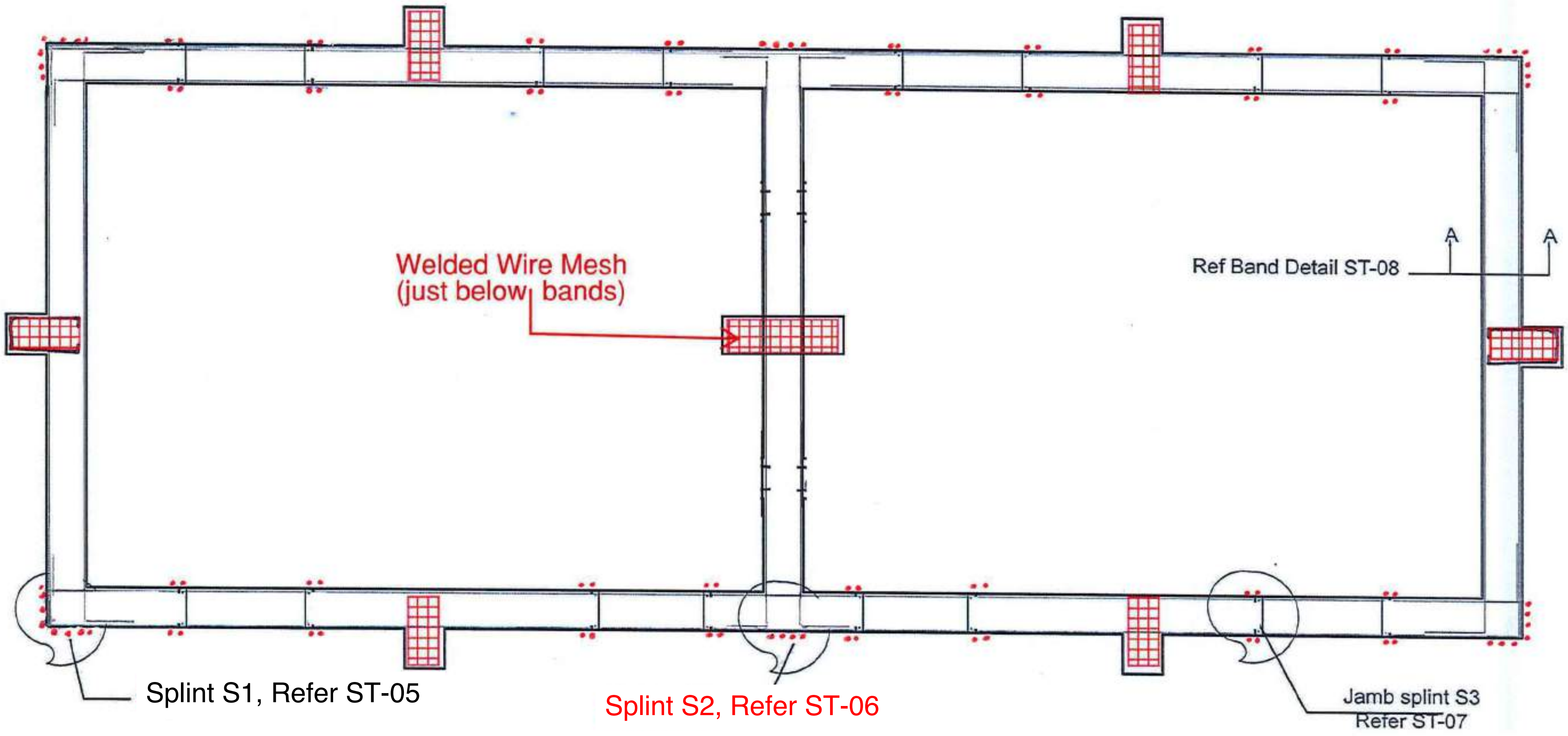
ONE STOREY



Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:50	Date:2017-04-28	Sheet No.:
	Drawing Title:Trench Plan	Design By:		ST-01

Type 4: Block stone masonry with timber bands and wire containment

ONE STOREY

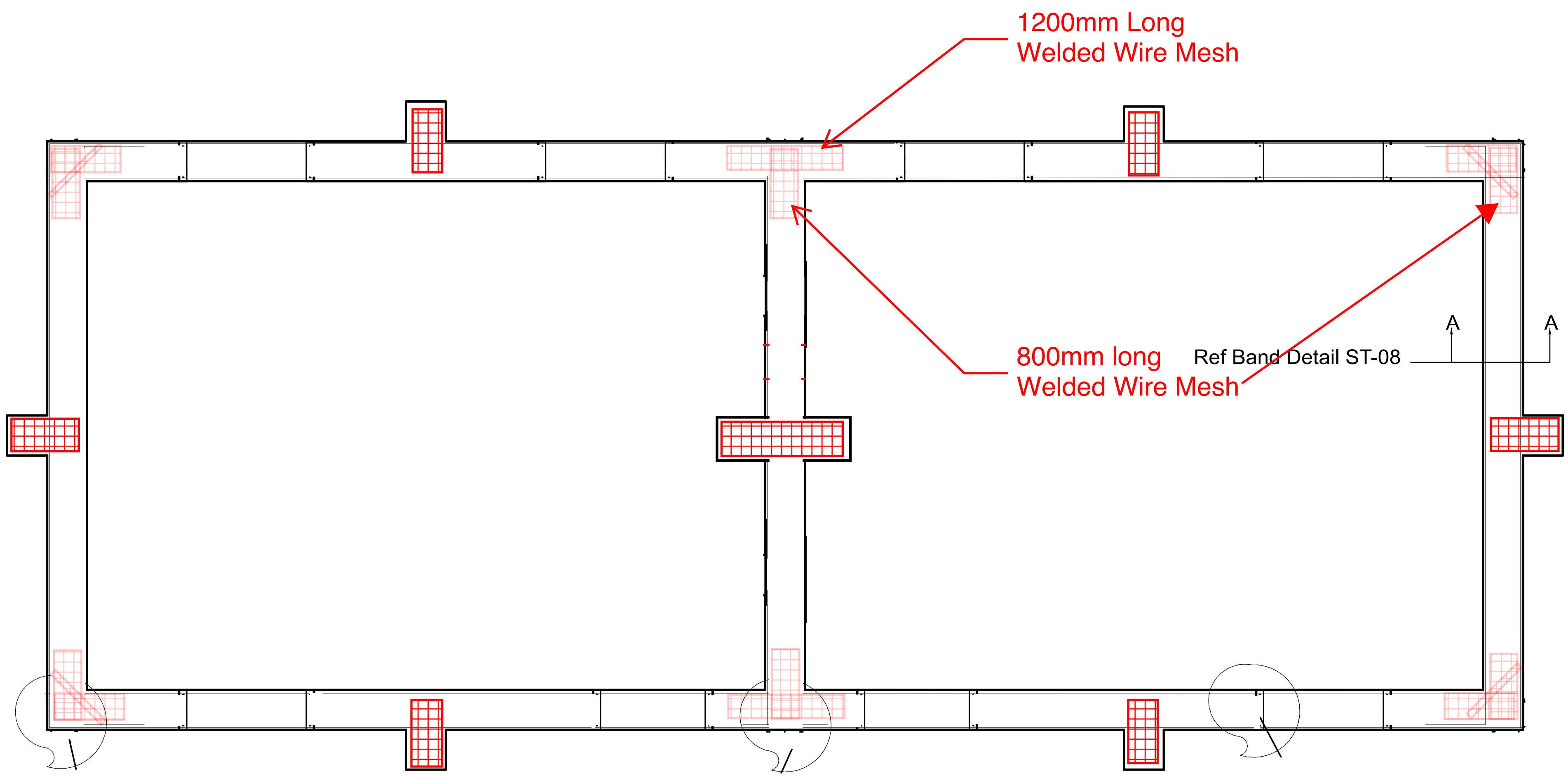


- Containment wires not shown for clarity
- Plinth band stirrups not shown for clarity
- Wires shown for splints are representative only
- If structurally possible, remove internal buttresses

Provide buttresses stitches at:
- Plinth, sill, lintel and eaves level
- Between plinth and sill
- Between lintel and eaves level

Central Level Project Implementation Unit **Ministry Of Education**	**Type: School Building Type Design for Remote Areas**	**Scale:**	**Date:**	Sheet No.:
	Title: Plinth band, vertical wires at wall junctions, jambs, and buttresses stitches	**Design By:**		ST-02

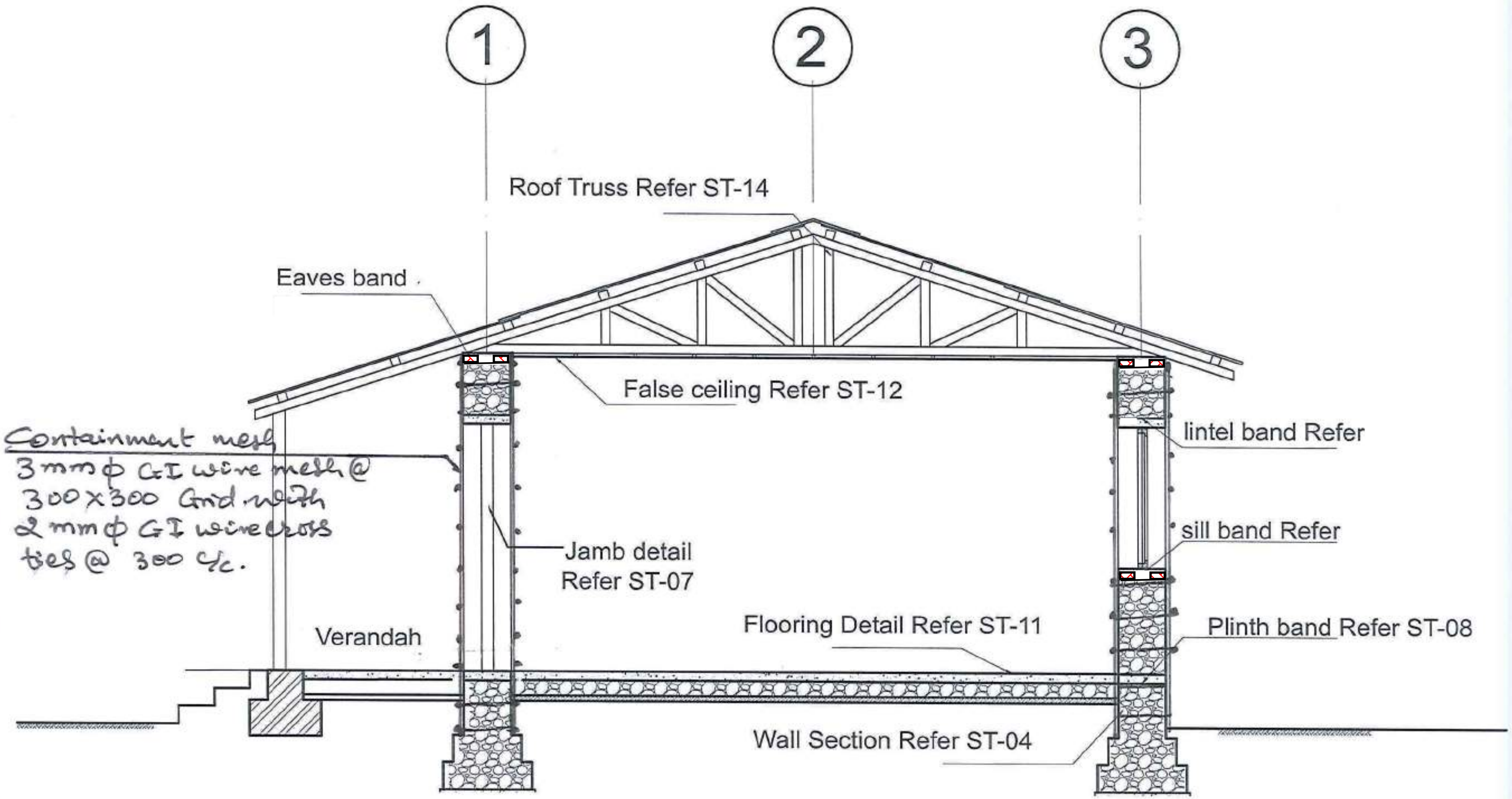
Type 4: Block stone masonry with timber bands and wire containment | **ONE STOREY**



- Welded Wire Mesh (WWM) placed between DPC and Sill Level, and Sill and Lintel Level, Ref Ar03 and Ar04
- WWM embedded in the mortar layer

Central Level Project Implementation Unit **Ministry Of Education**	**Type: School Building Type Design for Remote Areas**	**Scale:**	**Date:**
	Drawing Title: Stitch deatils	**Design By:**	Sheet No.: ST-02.

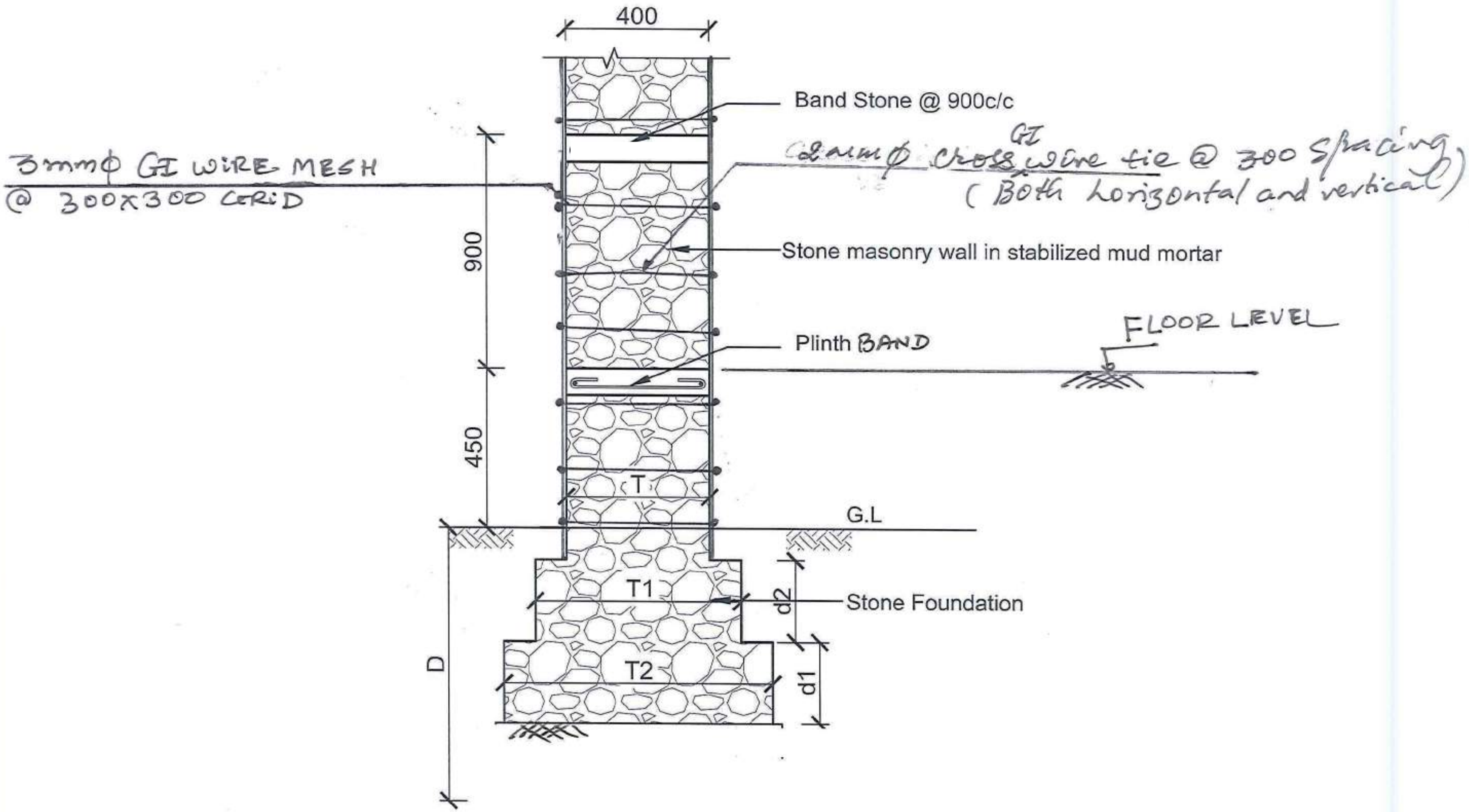
Type 4: Block stone masonry with timber bands and wire containment ONE STOREY



Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale:	Date:
	Drawing Title: Structural Section	Design By:	Sheet No.: ST-03

Type 4: Block stone masonry with timber bands and wire containment

ONE STOREY

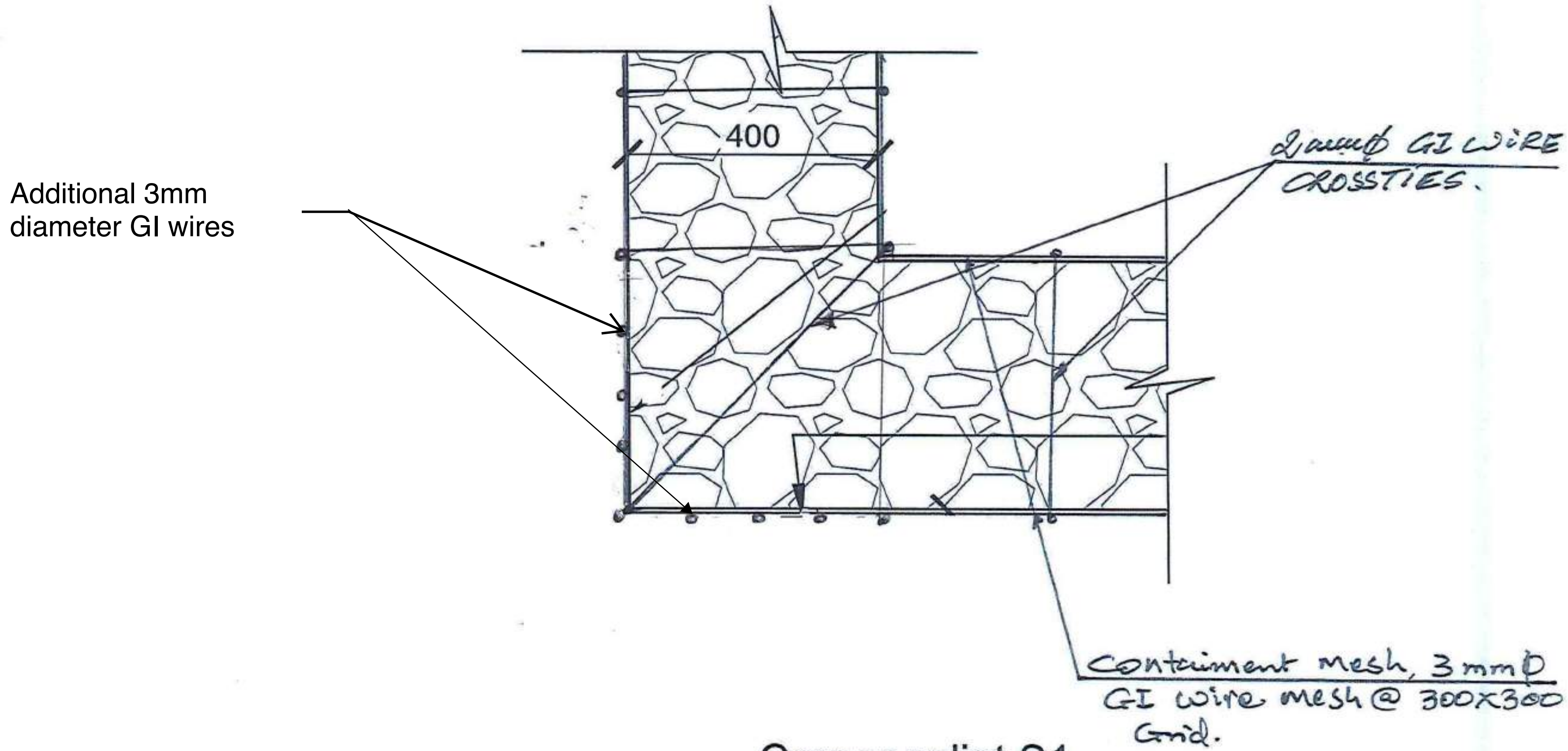


Wall Section (Foundation)

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale:	Date:	Sheet No.:
	Drawing Title:Wall Section Detail	Design By:		ST-04

Type 4: Block stone masonry with timber bands and wire containment

ONE STOREY

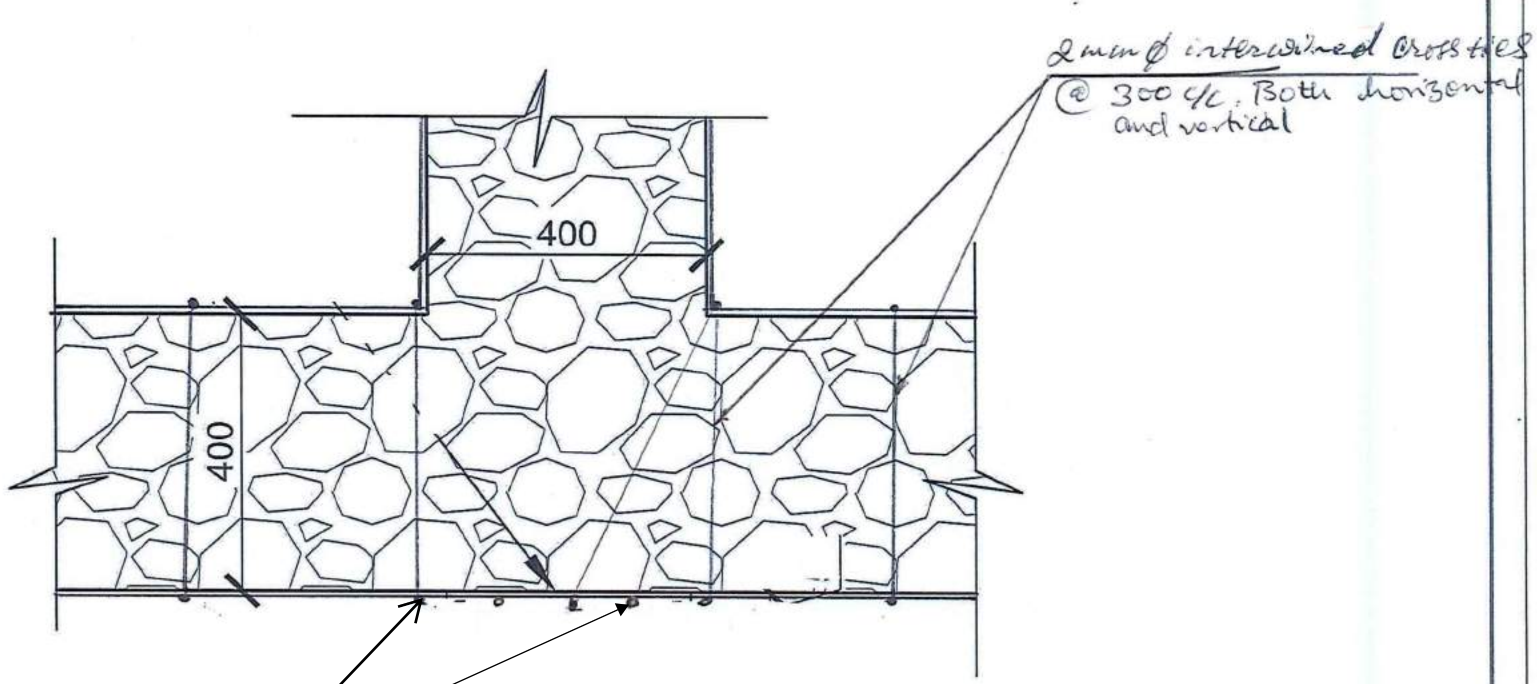


Corner splint S1

- Wires shown for splints are representative only

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:10	Date:2017-04-28	Sheet No.:
	Drawing Title:Corner Splint Detail	Design By:		ST-05

Type 4: Block stone masonry with timber bands and wire containment **ONE STOREY**



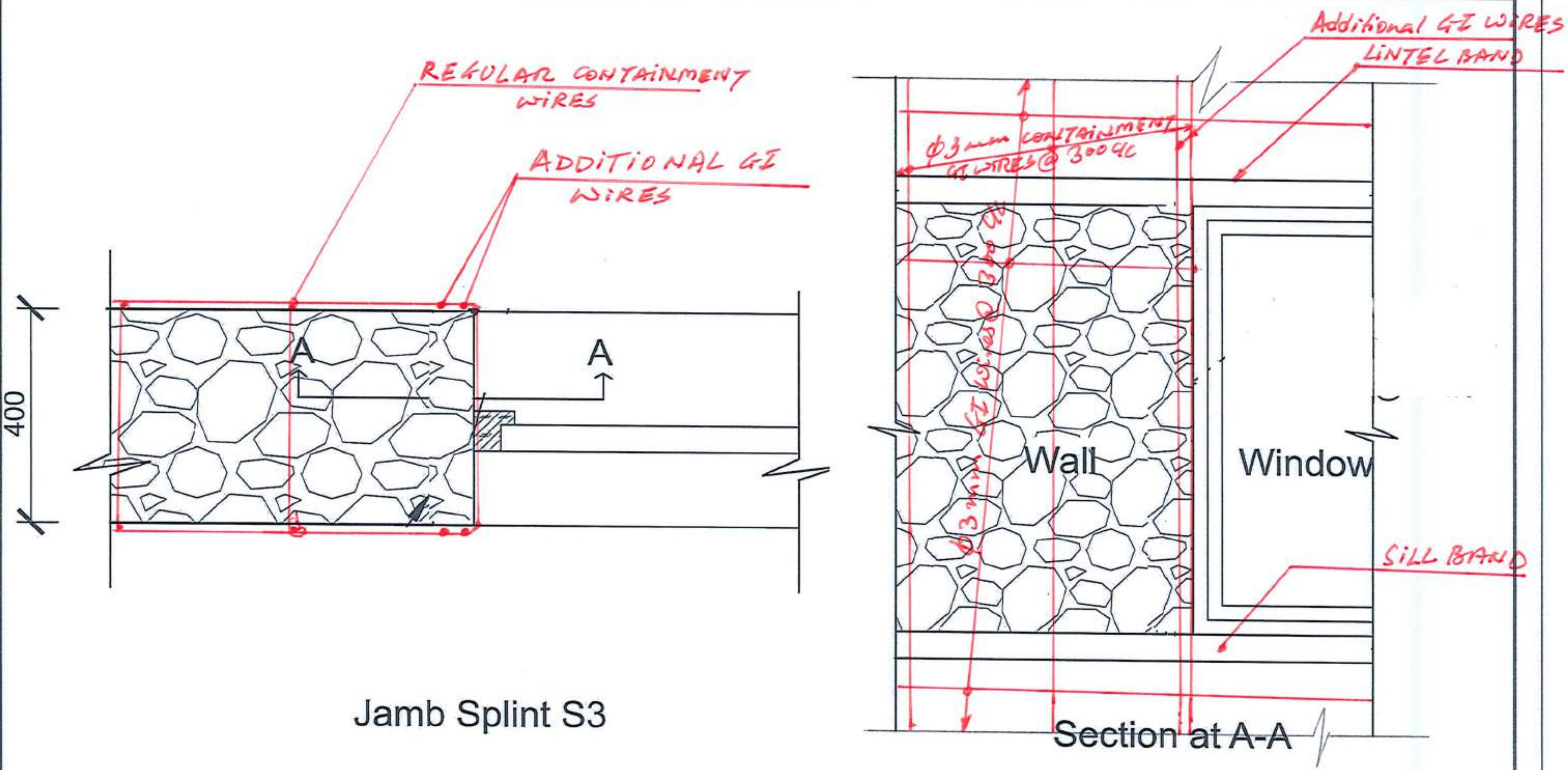
T- Junction Splint S2

- Wires shown for splints are representative only

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale:	Date:	Sheet No.:
	Drawing Title:T-Junction Splint Detail	Design By:		ST-06

Type 4: Block stone masonry with timber bands and wire containment

ONE STOREY

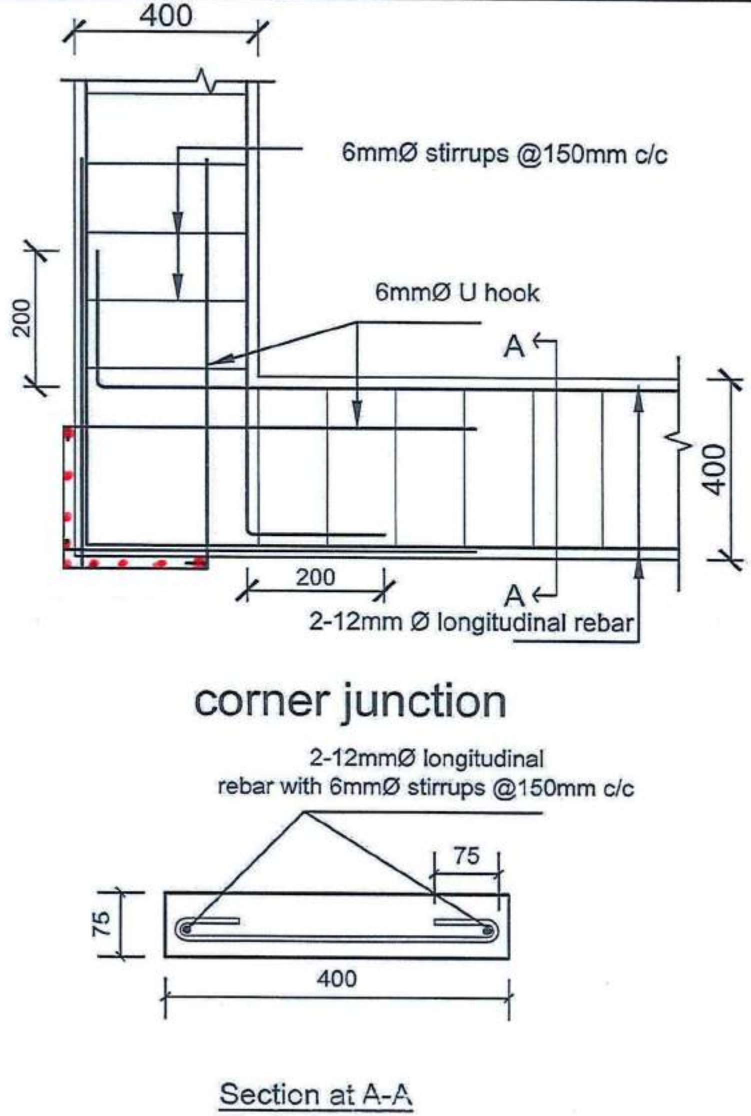


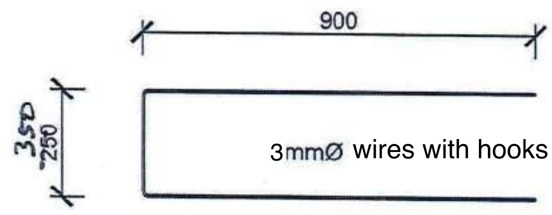
- Wires shown for splints are representative only

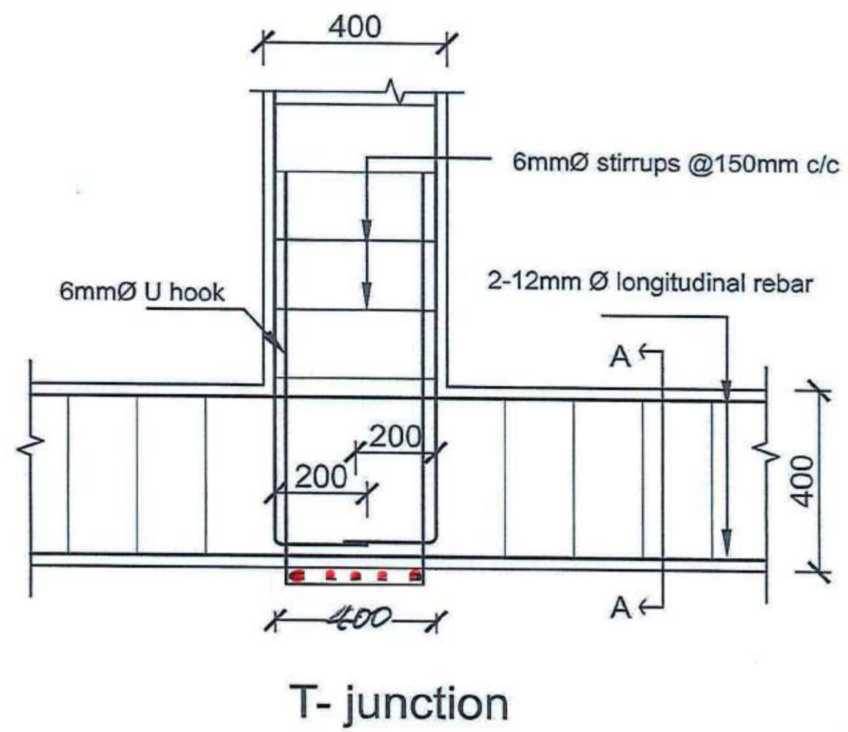
Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale:	Date::	Sheet No.:
	Drawing Title:Jamb Detail	Design By:		ST-07

Type 4: Block stone masonry with timber bands and wire containment

ONE STOREY





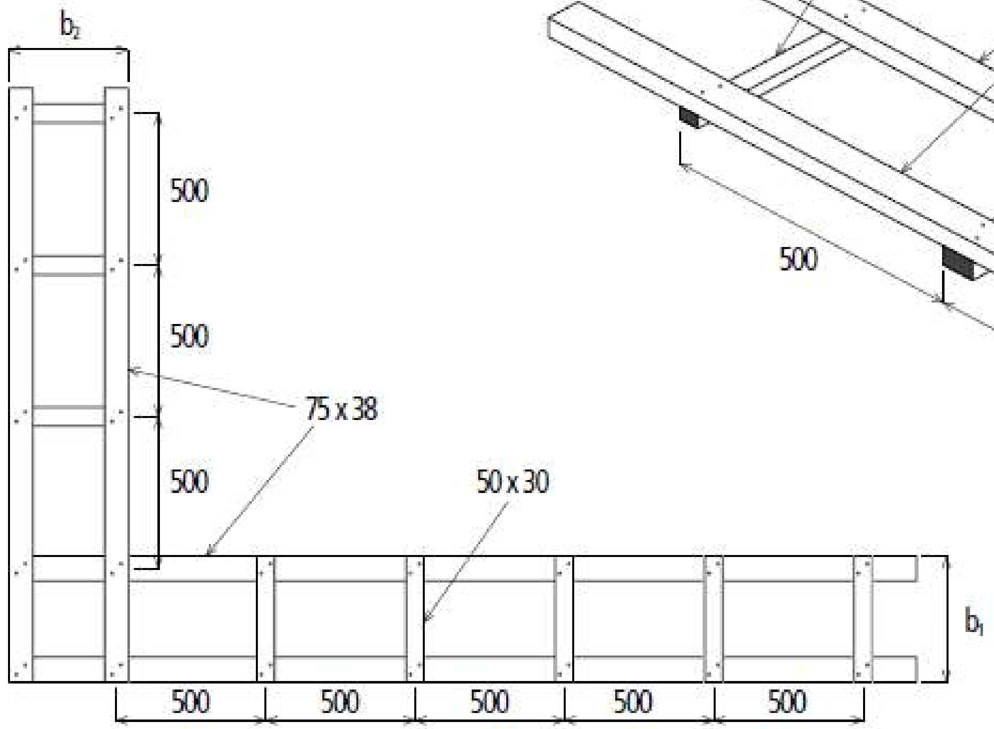


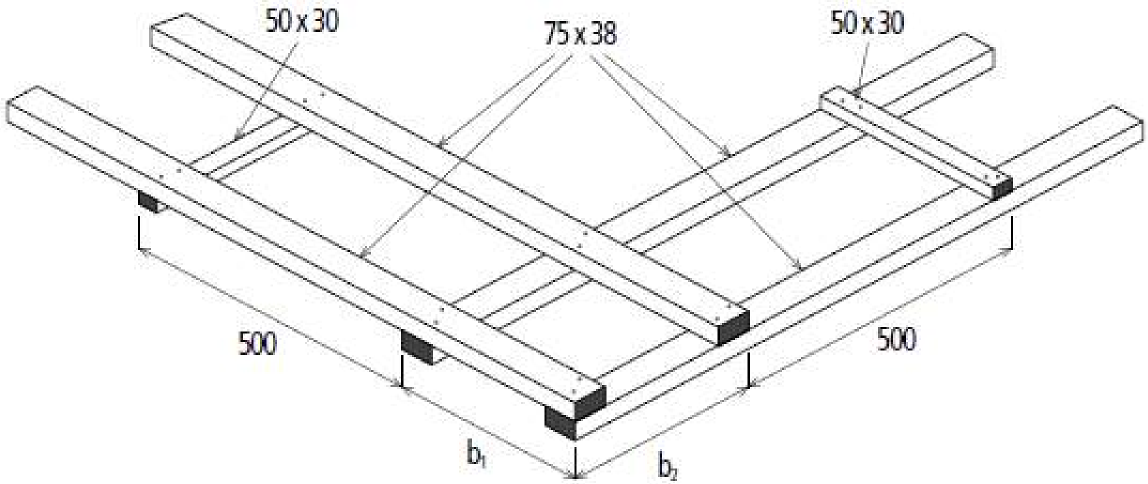
Containment wires not shown for clarity

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale:	Date:	Sheet No.:
	Drawing Title:Plinth	Design By:		ST-08

Type 4: Block stone masonry with timber bands and wire containment

ONE STOREY





b_1, b_2: wall thickness,
All dimensions are in mm.

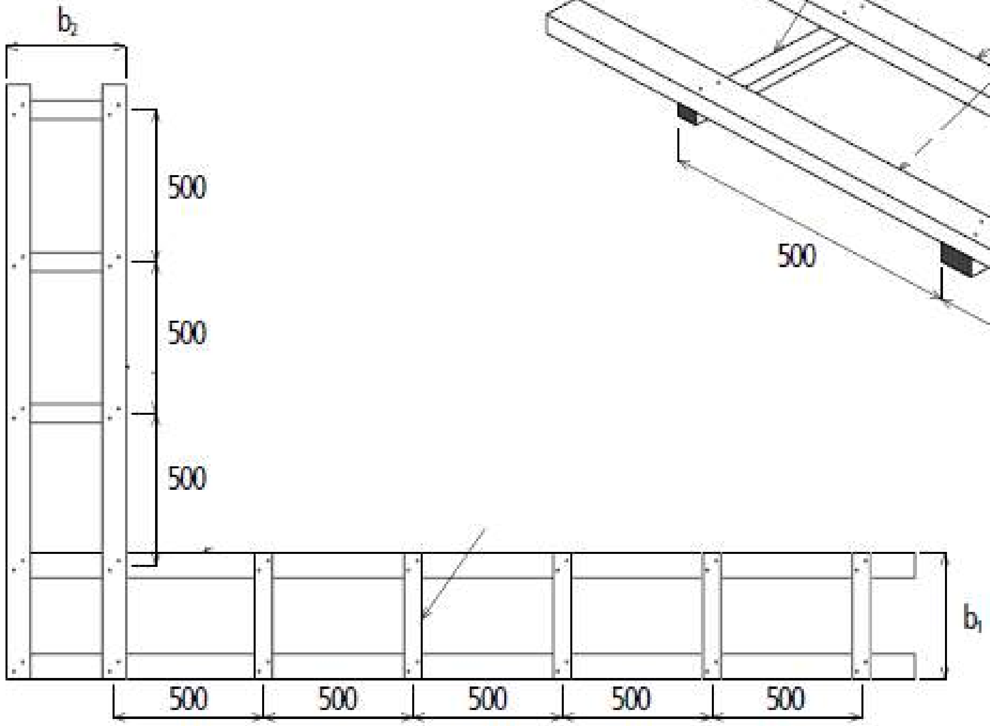
Adopted from AIEE, 2013

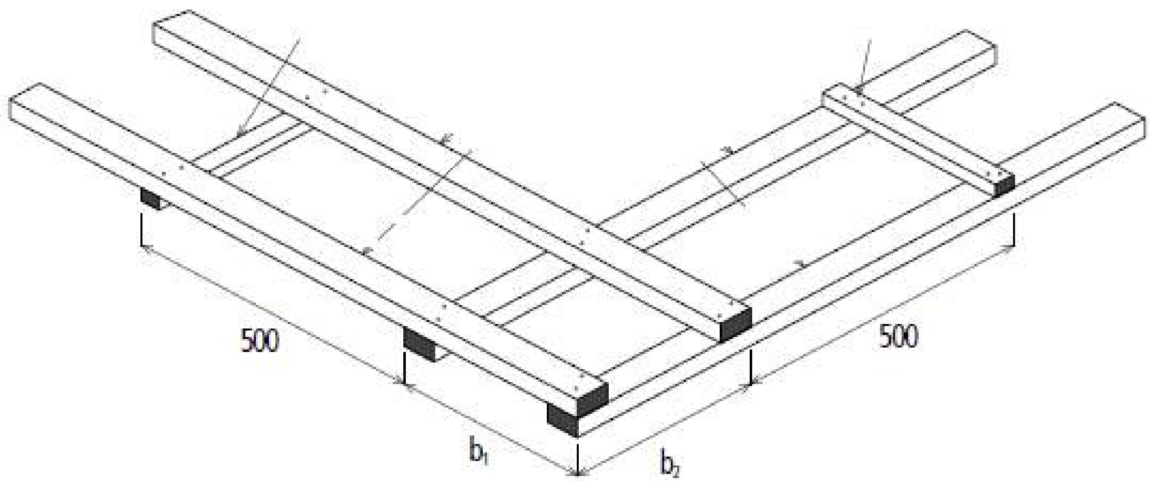
Proposal for alternative band details are encouraged.

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale:		Sheet No.: ST-09
	Drawing Title:Lintel Band Detail	Design By:		

Type 4: Block stone masonry with timber bands and wire containment

ONE STOREY





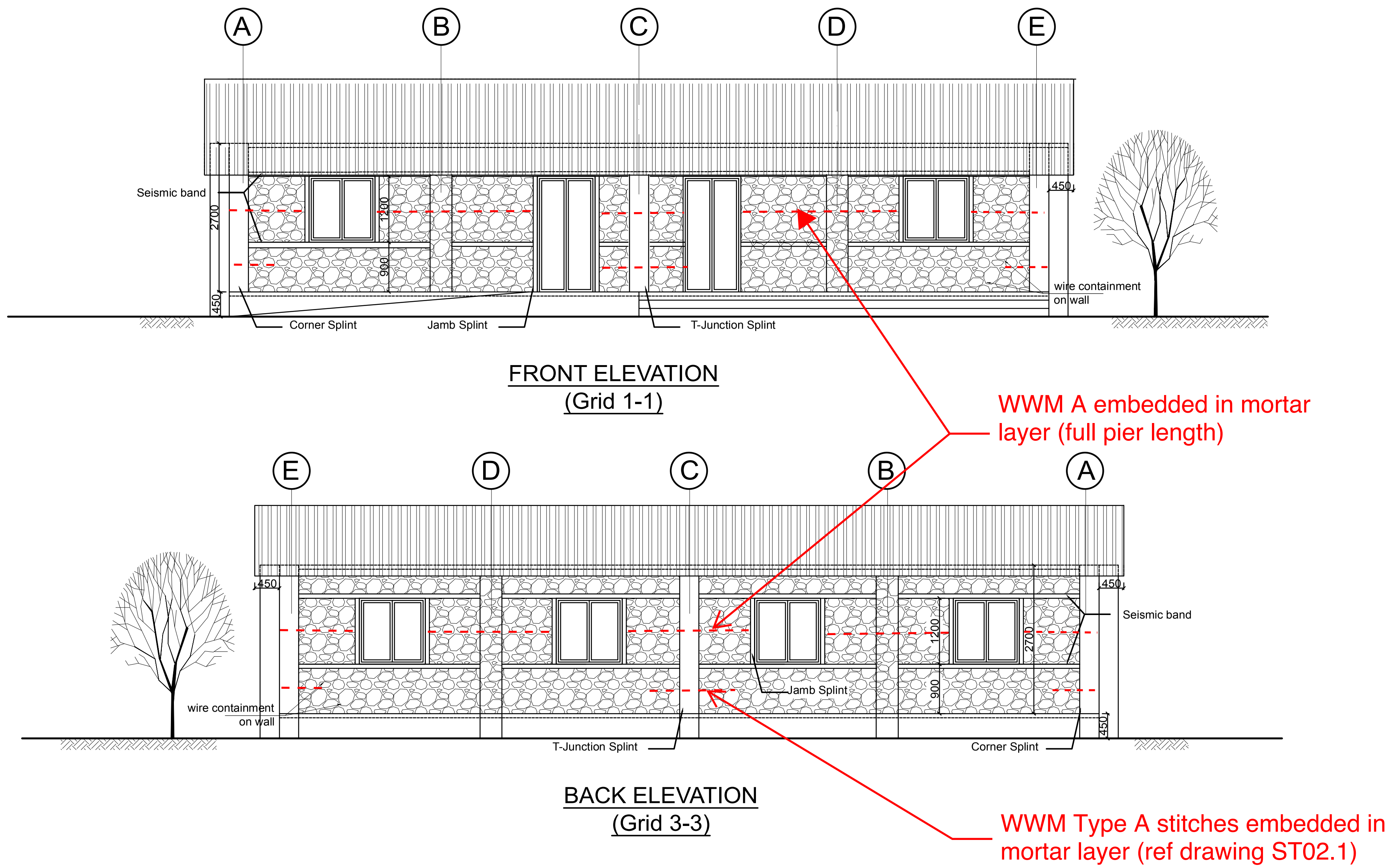
b_1, b_2: wall thickness,
All dimensions are in mm.

Adopted from IAEE, 2013

Proposal for alternative band details are encouraged.

Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale:	Date:	Sheet No.:
	Drawing Title:Eaves Band Detail	Design By:		ST-10

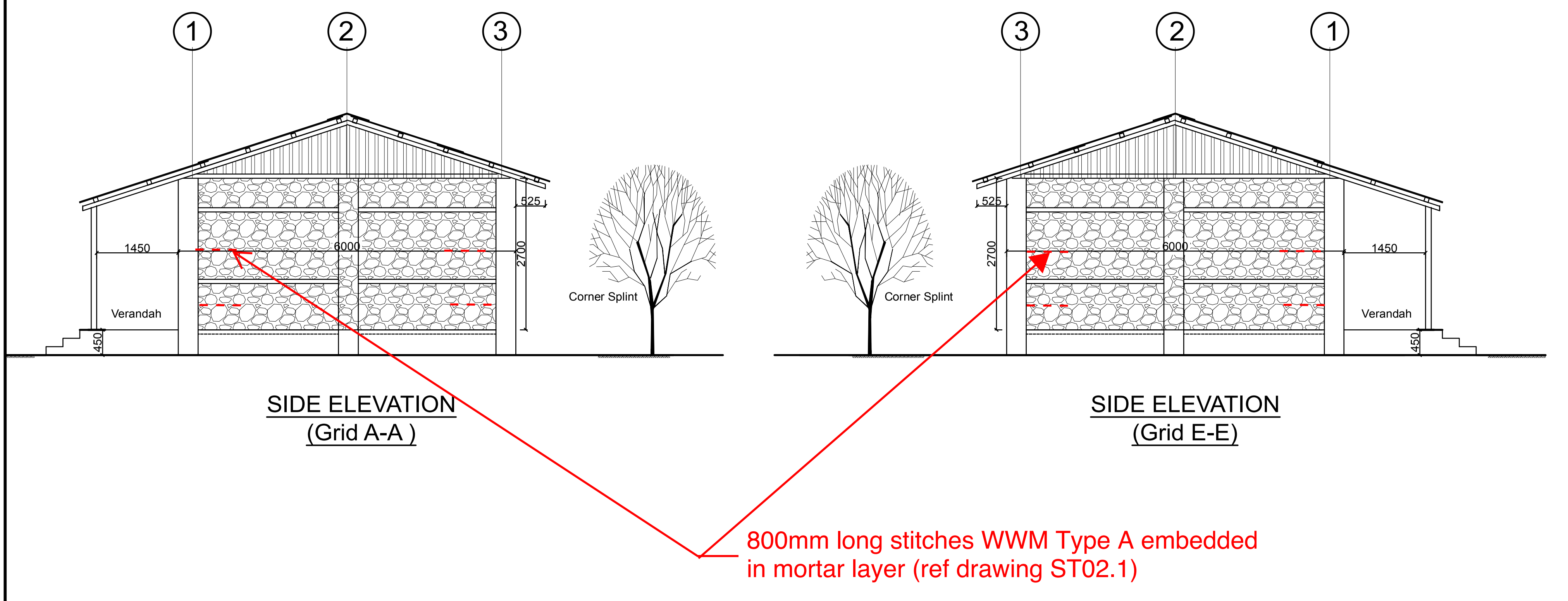
Type 4: Block stone masonry with timber bands and wire containment **ONE STOREY**



Central Level Project Implementation Unit Ministry Of Education	Type: School Building Type Design for Remote Areas	Scale: 1:100	Date:	Sheet No.: AR-03
	Drawing Title: Stitches	Design By:		

Type 4: Block stone masonry with timber bands and wire containment

ONE STOREY



Central Level Project Implementation Unit **Ministry Of Education**	**Type: School Building Type Design for Remote Areas**	**Scale:**	**Date:**	Sheet No.:
	Drawing Title:Elevations	**Design By:**		AR-04

Appendix B1 – Mortar Cubes Compression Test Data

(Type Design 1)

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Mud Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 1 (One Third)**
Level: Between Plinth and Sill Level

Asian Development Bank Project

Sample Casting Date: 10/01/2018
Sample Testing Date: 12/02/2018

S. No.	Identification	Load (Tons)	Crushing Strength (psi)
1	MM 1	0.42	231
2	MM 2	0.46	253
3	MM 3	0.62	342

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Mud Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 1 (Two Third)**
Level: Between Plinth and Sill Level

Asian Development Bank Project

Sample Casting Date: 12/01/2018
Sample Testing Date: 12/02/2018

S. No.	Identification	Load (Tons)	Crushing Strength (psi)
1	MM 1	0.34	187
2	MM 2	0.38	209
3	MM 3	0.46	253

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Mud Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 1 (One Third)**
Level: Between Sill & Lintel Level

Asian Development Bank Project

Sample Casting Date: 23/01/2018
Sample Testing Date: 08/03/2018

S. No.	Identification	Load (Tons)	Crushing Strength (psi)	Average Compressive Strength (psi)
1	SL 1	0.38	209	238
2	SL 2	0.51	281	
3	SL 3	0.41	226	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Mud Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 1 (One Third)**
Level: Between Lintel & Eaves Level

Asian Development Bank Project

Sample Casting Date: 07/02/2018
Sample Testing Date: 08/03/2018

S. No.	Identification	Load (Tons)	Crushing Strength (psi)	Average Compressive Strength (psi)
1	LE 1	0.57	314	383
2	LE 2	0.71	385	
3	LE 3	0.82	451	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Mud Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 1 (Two Third)**
Level: Between Sill and Lintel Level

Asian Development Bank Project

Sample Casting Date: 28/01/2018
Sample Testing Date: 08/03/2018

S. No.	Identification	Load (Tons)	Crushing Strength (psi)	Average Compressive Strength (psi)
1	SL 1	0.40	220	196
2	SL 2	0.36	198	
3	SL 3	0.31	171	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Mud Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 1 (Two Third)**
Level: Between Lintel & Eaves Level

Asian Development Bank Project

Sample Casting Date: 08/02/2018
Sample Testing Date: 08/03/2018

S. No.	Identification	Load (Tons)	Crushing Strength (psi)	Average Compressive Strength (psi)
1	EL 1	0.43	237	220
2	LE 2	0.31	170	
3	LE 3	0.46	253	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

Appendix B2 – Mortar Cubes Compression Test Data

(Type Design 2)

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Unstabilized Mud Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 2 (Two Third)**
Level: Between Plinth & Sill Level

Asian Development Bank Project

Sample Casting Date: 02/06/2018
Sample Testing Date: 03/07/2018

S. No.	Identification	Load (Tons)	Crushing Strength psi (MPa)	Average Compressive Strength psi (MPa)
1	PS 1	0.56	310 (2.13)	308 (2.1)
2	PS 2	0.58	325 (2.24)	
3	PS 3	0.52	290 (2)	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Unstabilized Mud Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 2 (Two Third)**
Level: Sill and Lintel Level

Asian Development Bank Project

Sample Casting Date: 11/06/2018
Sample Testing Date: 10/07/2018

S. No.	Identification	Load (Tons)	Crushing Strength psi (MPa)	Average Compressive Strength psi (MPa)
1	SL 1	0.58	320 (2.20)	307 (2.11)
2	SL 2	0.55	305 (2.10)	
3	SL 3	0.54	298 (2.05)	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Unstabilized Mud Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 2 (Two Third)**
Level: Lintel and Eaves Level

Asian Development Bank Project

Sample Casting Date: 26/06/2018
Sample Testing Date: 27/07/2018

S. No.	Identification	Load (Tons)	Crushing Strength psi (MPa)	Average Compressive Strength psi (MPa)
1	LE 1	0.50	280 (1.93)	277 (1.91)
2	LE 2	0.52	288 (1.98)	
3	LE 3	0.48	264 (1.82)	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Unstabilized Mud Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 2 (One Third)**
Level: Between Plinth & Sill Level

<u>Asian Development Bank Project</u>

Sample Casting Date: 04/07/2018
Sample Testing Date: 03/08/2018

S. No.	Identification	Load (Tons)	Crushing Strength psi (MPa)	Average Compressive Strength psi (MPa)
1	PS 1	0.50	280 (1.93)	285 (1.96)
2	PS 2	0.48	265 (1.82)	
3	PS 3	0.56	310 (2.13)	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Unstabilized Mud Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 2 (One Third)**
Level: Sill and Lintel Level

Asian Development Bank Project

Sample Casting Date: 12/07/2018
Sample Testing Date: 15/07/2018

S. No.	Identification	Load (Tons)	Crushing Strength psi (MPa)	Average Compressive Strength psi (MPa)
1	SL 1	0.50	279 (1.92)	278 (1.92)
2	SL 2	0.53	292 (2.01)	
3	SL 3	0.48	264 (1.82)	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Unstabilized Mud Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 2 (One Third)**
Level: Lintel and Eaves Level

Asian Development Bank Project

Sample Casting Date: 24/07/2018
Sample Testing Date: 26/08/2018

S. No.	Identification	Load (Tons)	Crushing Strength psi (MPa)	Average Compressive Strength psi (MPa)
1	LE 1	0.50	277 (1.91)	277 (1.91)
2	LE 2	0.53	291 (2.00)	
3	LE 3	0.48	263 (1.81)	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

Appendix B3 – Mortar Cubes Compression Test Data

(Type Design 3)

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Cement Stabilized Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 3 (One Third)**
Level: Between Plinth and Sill Level

Asian Development Bank Project

Sample Casting Date: 01/08/2018
Sample Testing Date: 31/10/2018

S. No.	Identification	Load (Tons)	Compressive Strength, psi (MPa)	Average Compressive Strength, psi (MPa)
1	PS 1	0.12	66.12 (0.456)	58.77 (0.405)
2	PS 2	0.07	38.57 (0.266)	
3	PS 3	0.13	71.63 (0.494)	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Cement Stabilized Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 3 (One Third)**
Level: Between Sill and Lintel Level

Asian Development Bank Project

Sample Casting Date: 01/10/2018
Sample Testing Date: 31/10/2018

S. No.	Identification	Load (Tons)	Compressive Strength, psi (MPa)	Average Compressive Strength, psi (MPa)
1	SL 1	0.27	148.77 (1.026)	147.28 (1.01)
2	SL 2	0.28	154.28 (1.064)	
3	SL 3	0.25	138.81 (0.957)	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Cement Stabilized Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 3 (Two Third)**
Level: Between Plinth to Sill Level

<u>Asian Development Bank Project</u>

Sample Casting Date: 08/10/2018
Sample Testing Date: 06/11/2018

S. No.	Identification	Load (Tons)	Compressive Strength, psi (MPa)	Average Compressive Strength, psi (MPa)
1	PS 1	0.05	27.55 (0.19)	33.06 (0.288)
2	PS 2	0.08	44.08 (0.304)	
3	PS 3	0.05	27.55 (0.19)	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Cement Stabilized Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 3 (Two Third)**
Level: Between Sill to Lintel Level

<u>Asian Development Bank Project</u>

Sample Casting Date: 08/10/2018
Sample Testing Date: 06/11/2018

S. No.	Identification	Load (Tons)	Compressive Strength, psi (MPa)	Average Compressive Strength, psi (MPa)
1	SL 1	0.14	77.14 (0.532)	75.5 (0.52)
2	SL 2	0.16	88.16 (0.608)	
3	SL 3	0.11	61.2 (0.42)	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Cement Stabilized Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 3 (Two Third)**
Level: Between Lintel & Eaves Level

<u>Asian Development Bank Project</u>

Sample Casting Date: 13/10/2018
Sample Testing Date: 09/11/2018

S. No.	Identification	Load (Tons)	Compressive Strength, psi (MPa)	Average Compressive Strength, psi (MPa)
1	LE 1	0.09	49.59 (0.342)	44.08 (0.304)
2	LE 2	0.07	38.57 (0.266)	
3	LE 3	0.08	44.08 (0.304)	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

Appendix B4 – Mortar Cubes Compression Test Data

(Type Design 4)

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Mud Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 4 (One Third)**
Level: Between Plinth and Sill Level

Asian Development Bank Project

Sample Casting Date: 14/03/2018
Sample Testing Date: 25/04/2018

S. No.	Identification	Load (Tons)	Crushing Strength (psi)	Average Compressive Strength (psi)
1	PS 1	0.43	236	218
2	PS 2	0.37	203	
3	PS 3	0.39	215	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Mud Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 4 (One Third)**
Level: Between Sill and Lintel Level

Asian Development Bank Project

Sample Casting Date: 24/03/2018
Sample Testing Date: 25/04/2018

S. No.	Identification	Load (Tons)	Crushing Strength (psi)	Average Compressive Strength (psi)
1	SL 1	0.39	215	197
2	SL 2	0.25	138	
3	SL 3	0.43	237	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Mud Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 4 (One Third)**
Level: Between Lintel and Eaves Level

<u>Asian Development Bank Project</u>

Sample Casting Date: 06/04/2018
Sample Testing Date: 25/04/2018

S. No.	Identification	Load (Tons)	Crushing Strength (psi)	Average Compressive Strength (psi)
1	LE 1	0.23	127	171
2	LE 2	0.31	171	
3	LE 3	0.39	215	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Mud Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 4 (Two Third)**
Level: Between Sill and Lintel Level

Asian Development Bank Project

Sample Casting Date: 29/03/2018
Sample Testing Date: 25/04/2018

S. No.	Identification	Load (Tons)	Crushing Strength (psi)	Average Compressive Strength (psi)
1	SL 1	0.39	215	268
2	SL 2	0.58	319	
3	SL 3	0.49	270	

Dr. Qaisar Ali
Incharge
Material Testing Lab.

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY PESHAWAR
MATERIAL TESTING LABORATORY

Test Report

Test: Compression Test of Mud Mortar Cubes
Agency: Dr. Naveed Ahmad, Assistant Professor, CED, UET Peshawar
Model Type: **Type 4 (Two Third)**
Level: Between Lintel and Eaves Level

Asian Development Bank Project

Sample Casting Date: 06/04/2018
Sample Testing Date: 25/04/2018

S. No.	Identification	Load (Tons)	Crushing Strength (psi)	Average Compressive Strength (psi)
1	LE 1	0.40	220	290
2	LE 2	0.72	397	
3	LE 3	0.46	253	

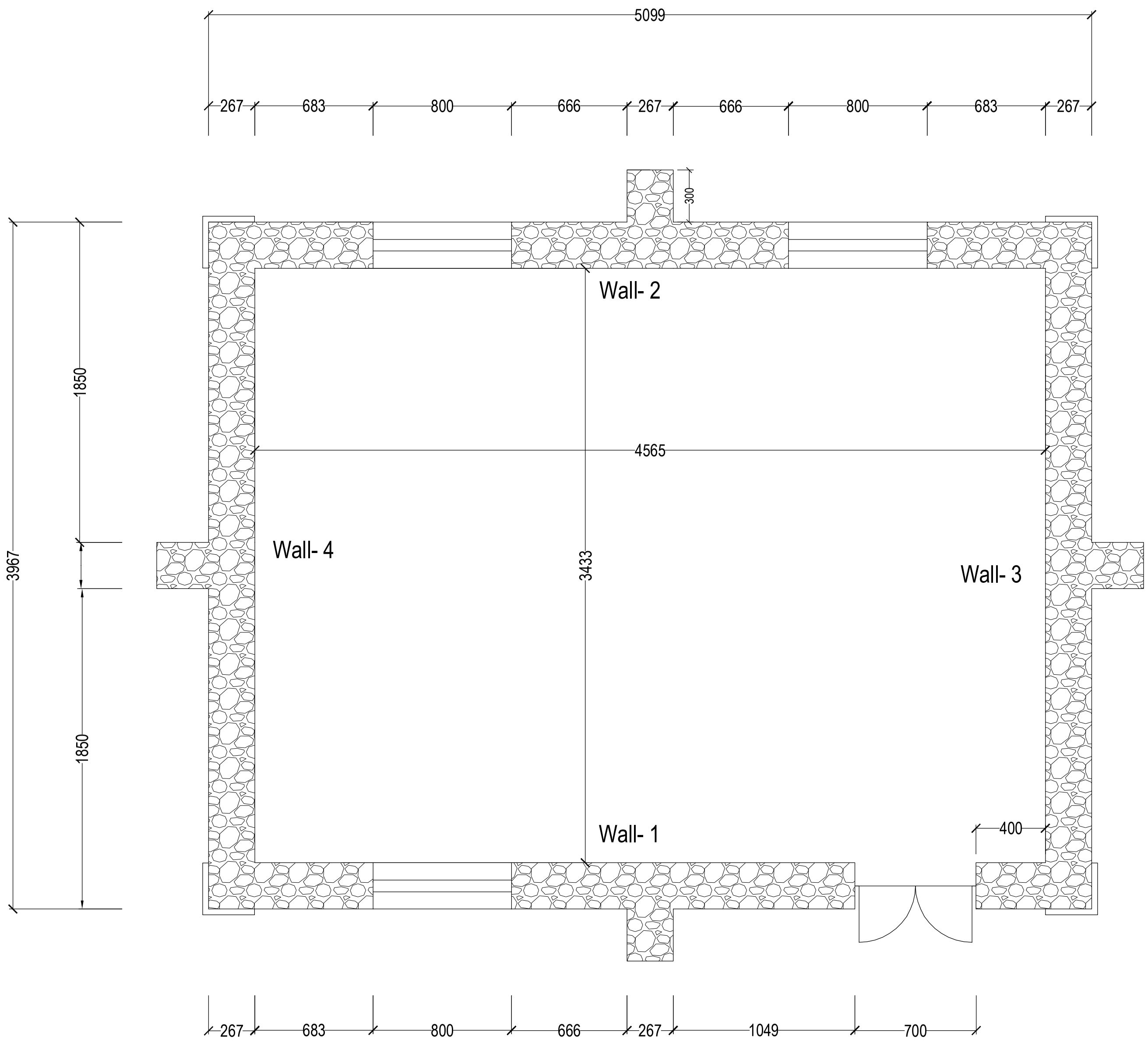
Dr. Qaisar Ali
Incharge
Material Testing Lab.

Appendix C1 – School Design Detailed Drawings-2/3rd Scale Model (Type Design 1)

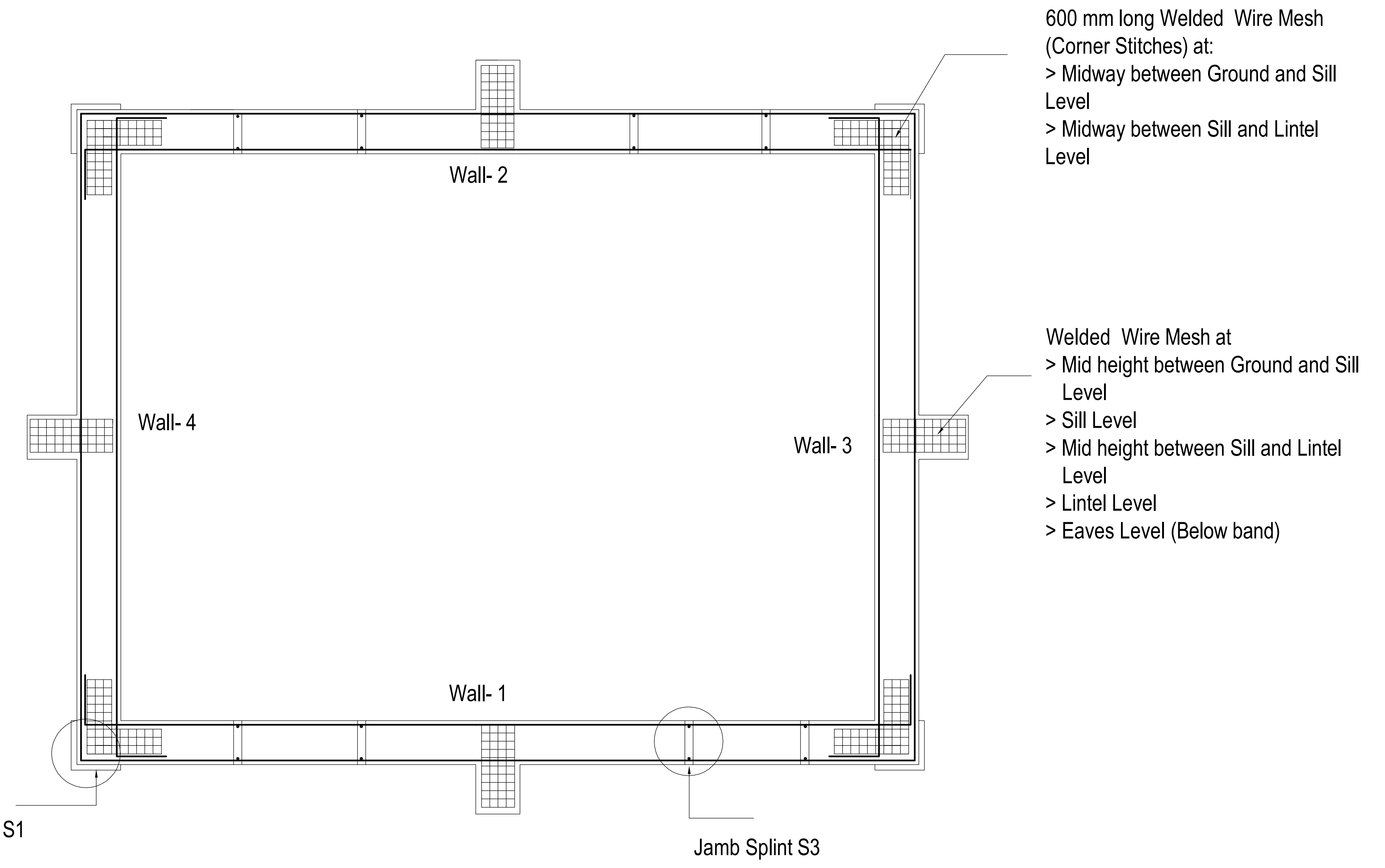
Proposed Two Third Drawings of Stone Masonry in Cement Stabilized Mud Mortar and RCC Bands

Type 1

Asian Development Bank

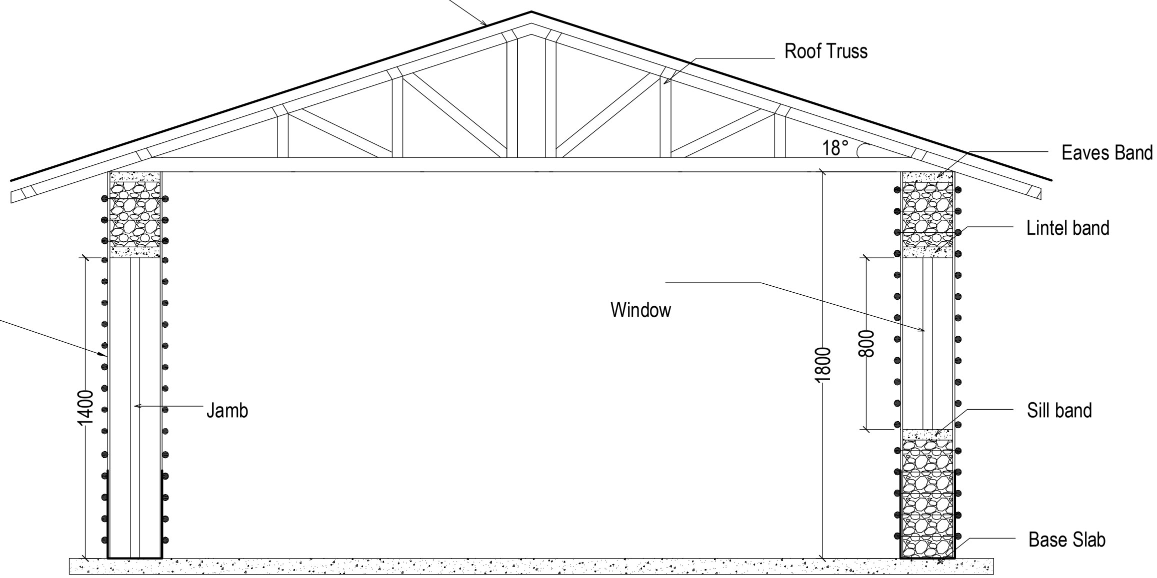


Consultant Name: University of Engineering and Technology Peshawar.	Client Name: Asian Development Bank	Design Type: Stone Masonry in Cement Stabilized Mortar and RCC Bands (Two Third Drawings) Type # 1	TITLE: FLOOR PLAN	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: December 2017 Scale: Read As Shown Dwg. No. 01



Note: Stirrups not shown for clarity.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (Two Third Drawings) Type # 1	Stitch Details Corner Splints Jamb Splints	Dr. Qaisar Ali Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: December 2017 Scale: Read As Shown Dwg. No. 02



At Ceiling band, the Vertical Wires of Containment of both the exterior and interior faces passes through the ceiling band at required development length and are intertwined together, (see fig:1).

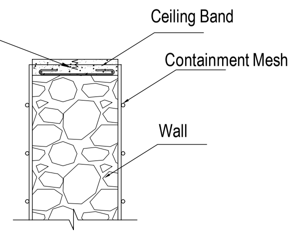
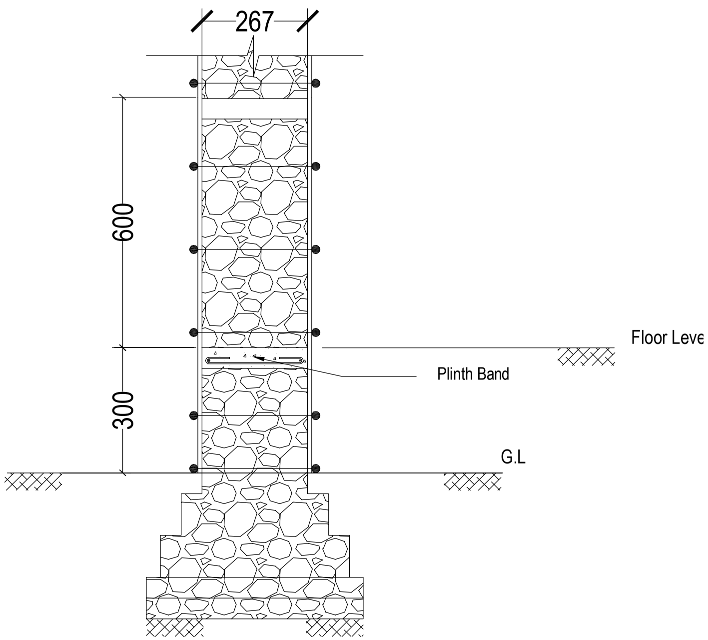


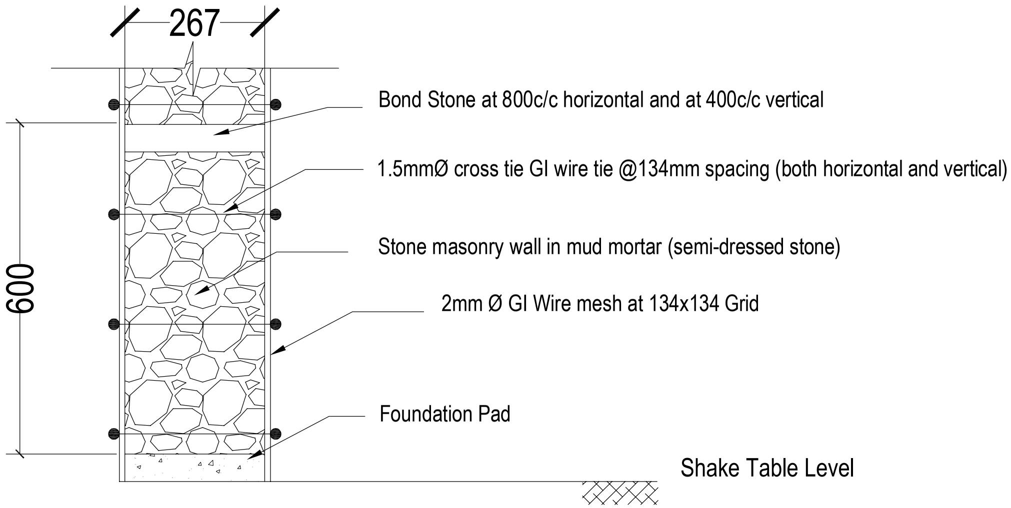
Figure: 01

Levels	
Ridge Level	+2693 mm
CeilingLevel	+1800 mm
Lintel Level	+1400 mm
Sill Level	+600 mm
Base Slab	+00 mm

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (Two Third Drawings) Type # 1	Structural Section	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: December 2017 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 03

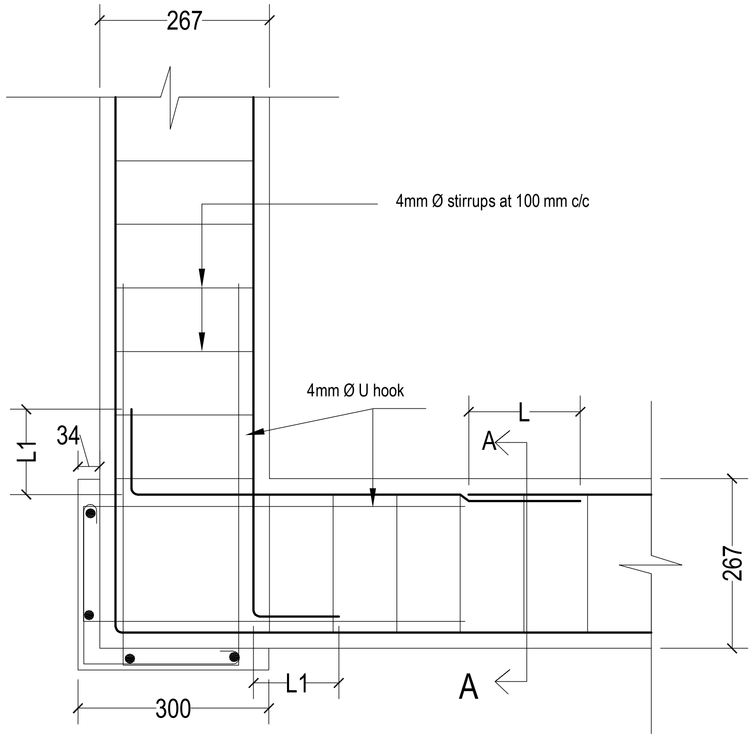


Wall Section
(Field Condition)



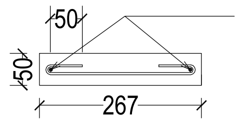
Wall Section
(Test Model in Lab)

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	ADB Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (Two Third Drawings) Type # 1	Wall Section	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: December 2017 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 04

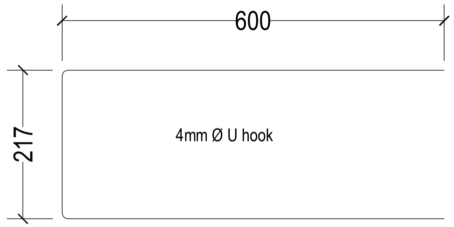


Note: Containment wires not shown for clarity.

Note: The scaling is based on bar diameter rather than x-sectional area.



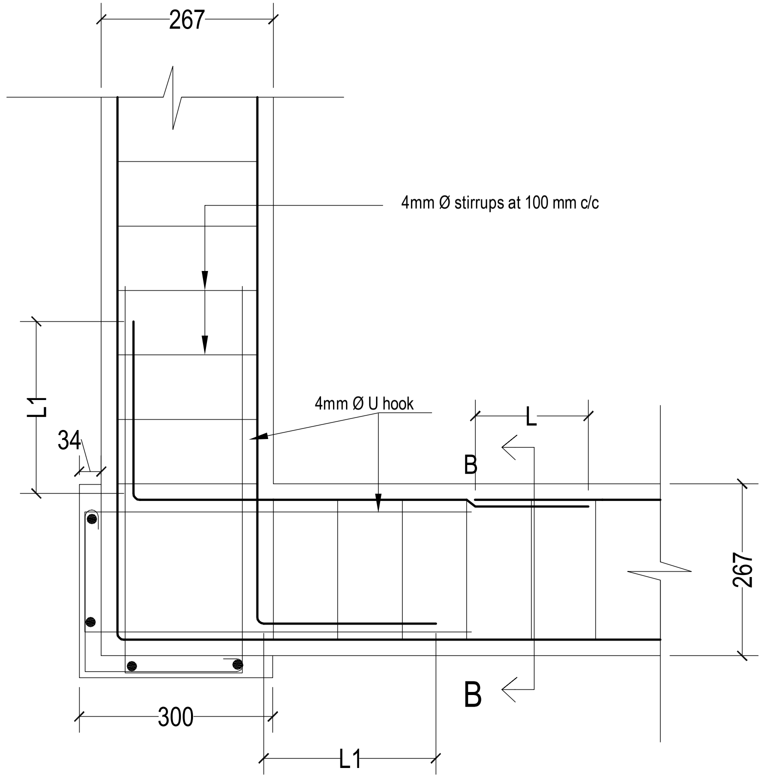
Section at A-A
Plinth, Sill Band



Bar Diameter Ø mm	Lap Length, L mm	Hook Length, L1 mm
8	440	215
11	600	375

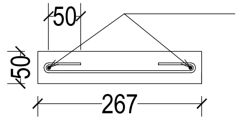
Corner Junction Plinth, Sill Band

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: December 2017
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (Two Third Drawings) Type # 1	Corner Junction at Plinth, Sill Band	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 05

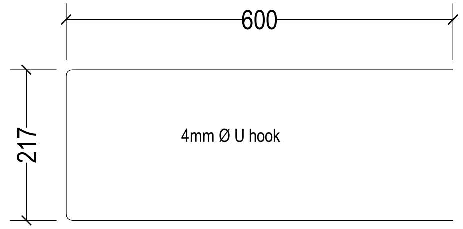


Note: Containment wires not shown for clarity.

Note: The scaling is based on bar diameter rather than x-sectional area.



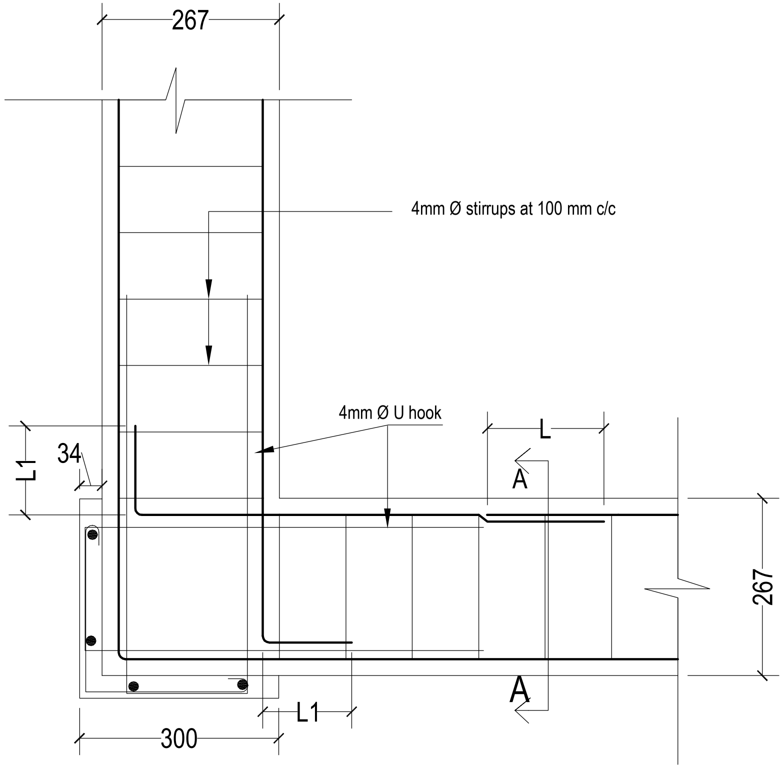
Section at B-B Lintel Band



Bar Diameter Ø mm	Lap Length, L mm	Hook Length, L1 mm
8	440	215
11	600	375

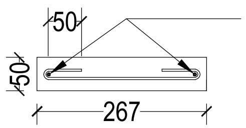
Corner Junction Lintel Band Detail

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: December 2017
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (Two Third Drawings) Type # 1	Corner Junction at Lintel Band Detail	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 06

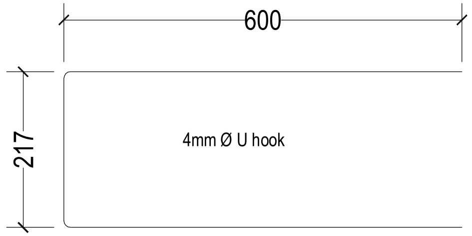


Note: Containment wires not shown for clarity.

Note: The scaling is based on bar diameter rather than x-sectional area.



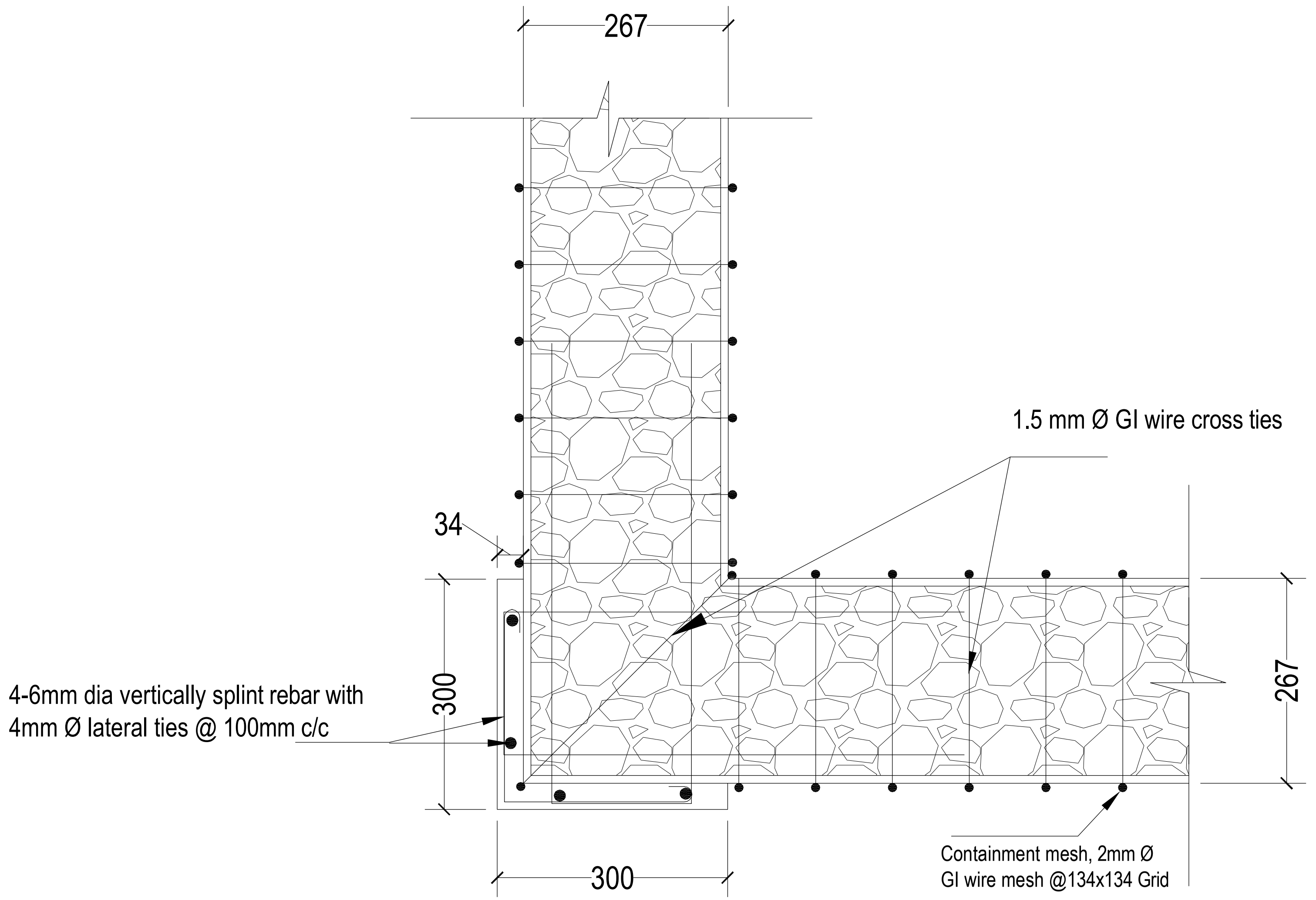
Section at A-A
Eaves Band



Bar Diameter Ø mm	Lap Length, L mm	Hook Length, L1 mm
8	440	215
11	600	375

Corner Junction Eaves Band Detail

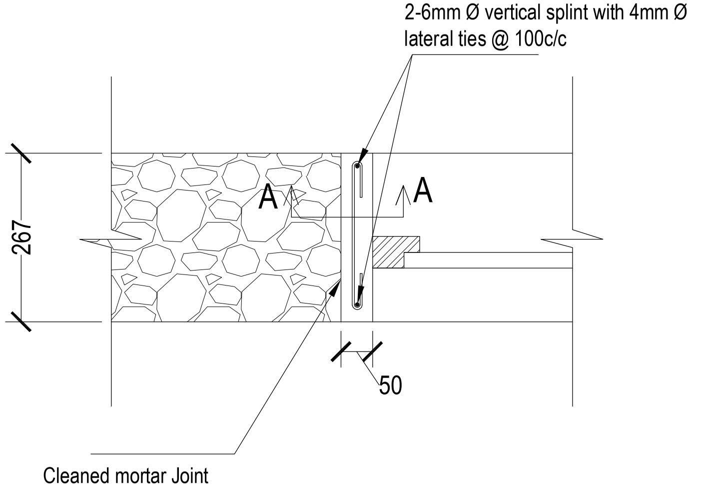
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (Two Third Drawings) Type # 1	Corner Junction at Eaves Band Detail	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: December 2017 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 07

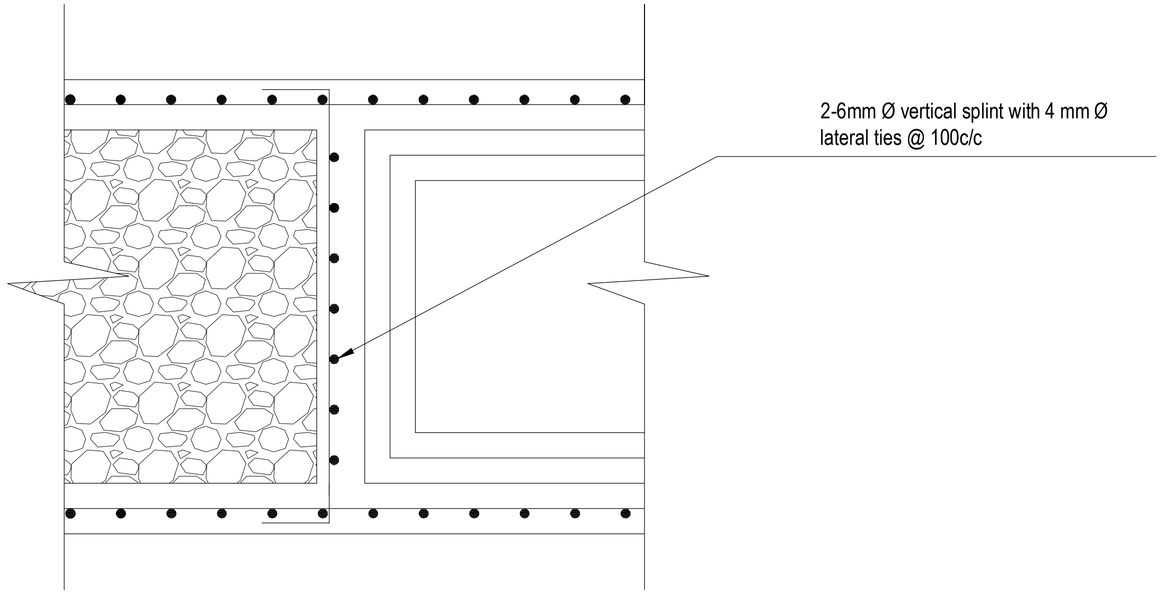


Corner Splint S1

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: December 2017
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (Two Third Drawings) Type # 1	Corner Splint S1 Detail	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 08

Note: The scaling is based on
bar diameter rather than area.

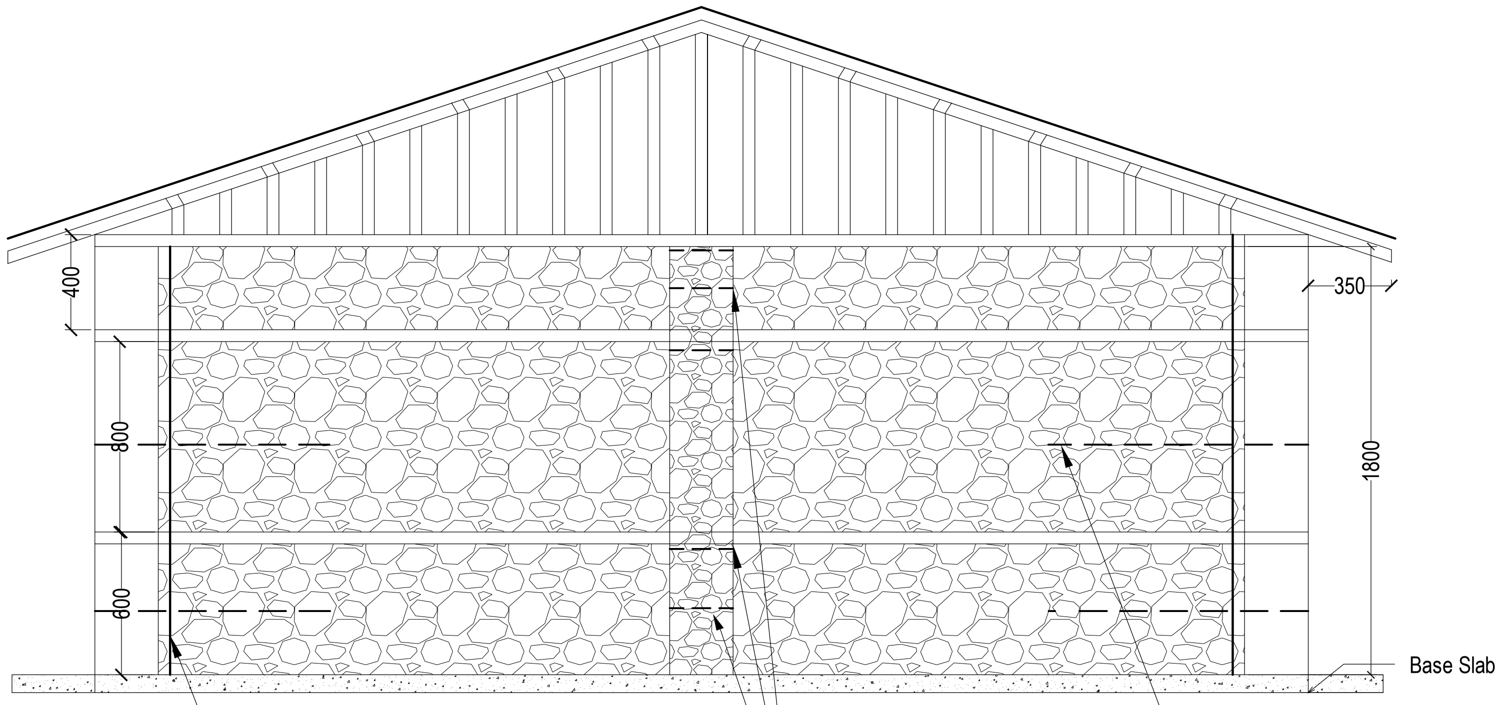




Section at A-A

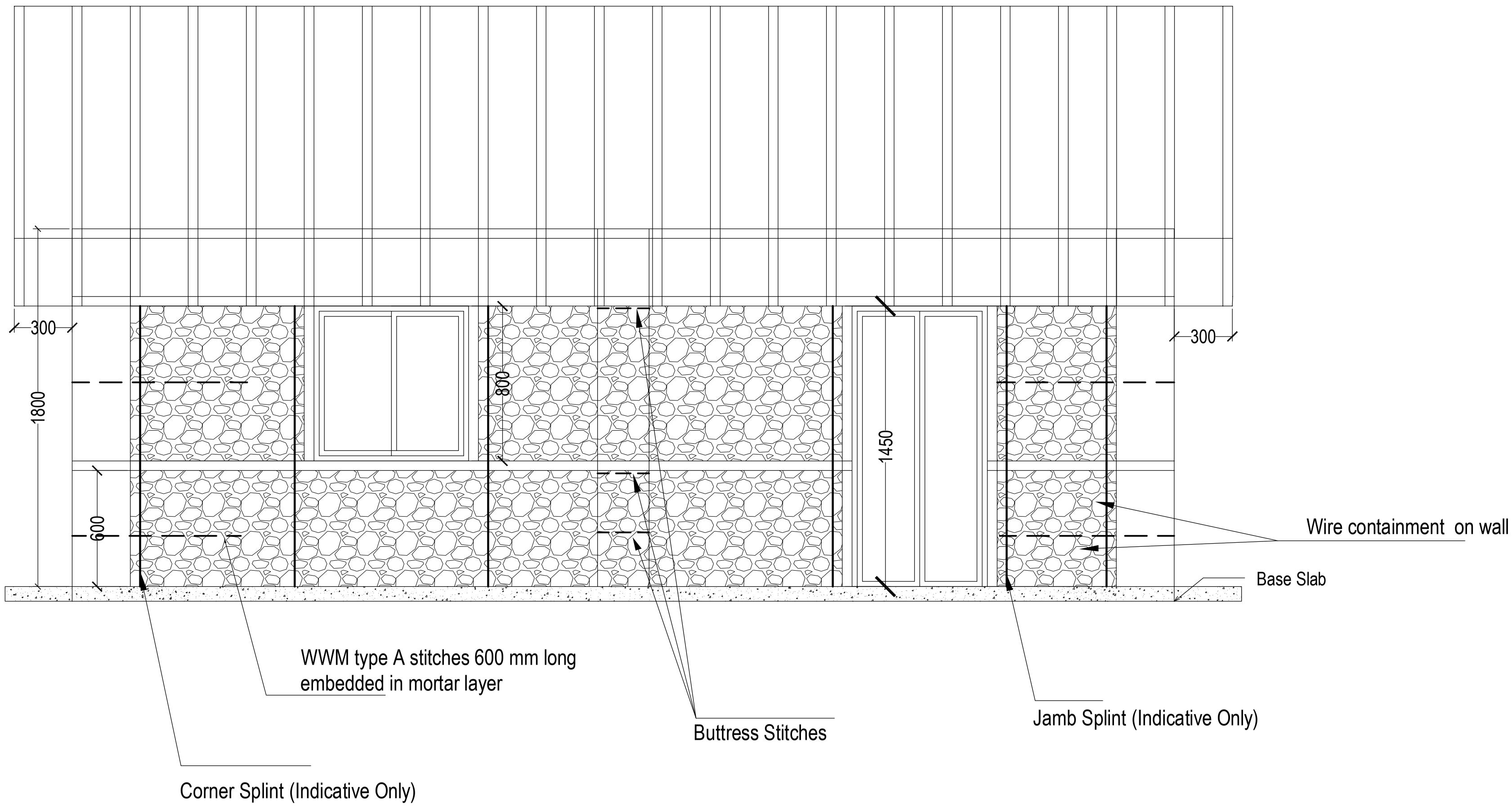
Jamb Splint S3

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: December 2017
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (Two Third Drawings) Type # 1	Jamb Splint S3 Detail	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 09



Side Elevation

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (Two Third Drawings) Type # 1	Side Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: December 2017 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 10



Front Elevation

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: December 2017
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (Two Third Drawings) Type # 1	Front Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 11

Back Elevation

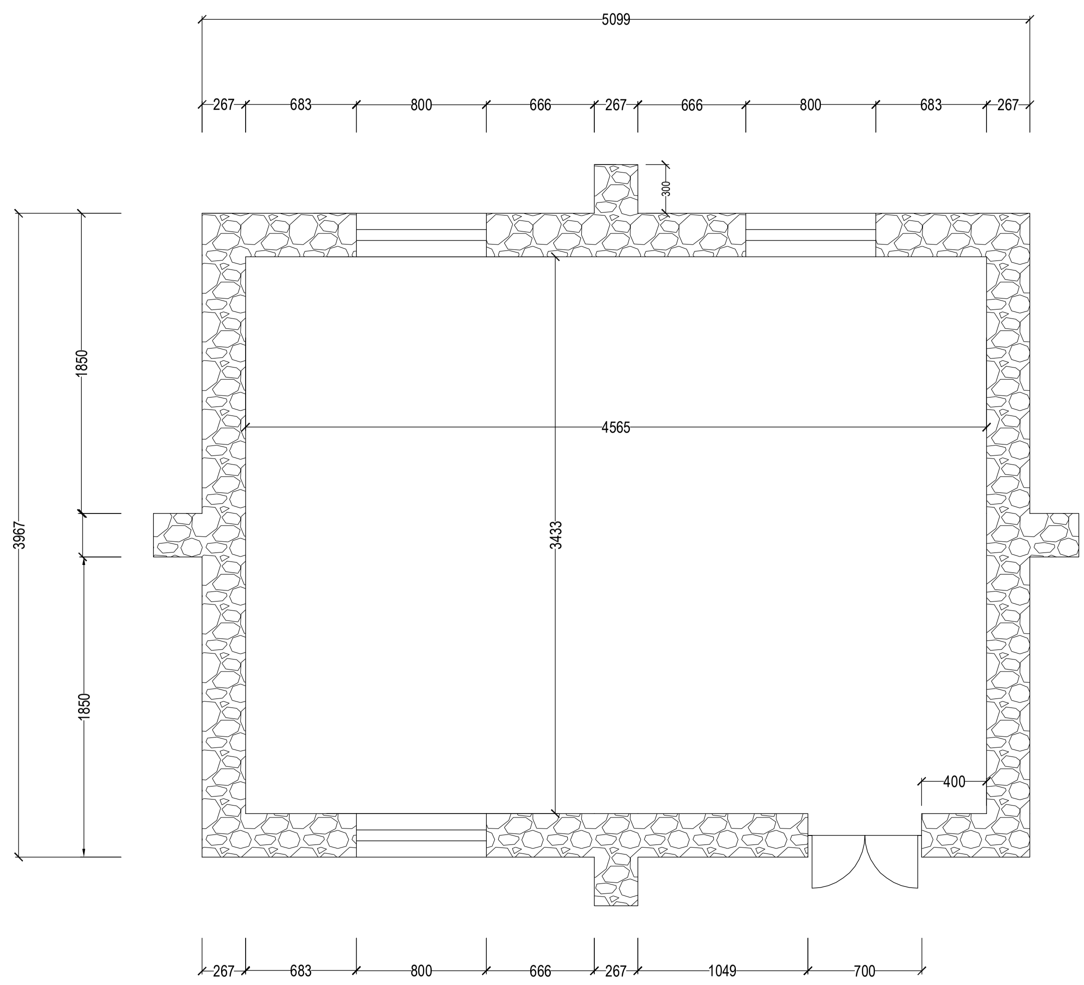
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	ADB Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (Two Third Drawings) Type # 1	Back Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: December 2017 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 12

Appendix C2 – School Design Detailed Drawings-2/3rd Scale Model (Type Design 2)

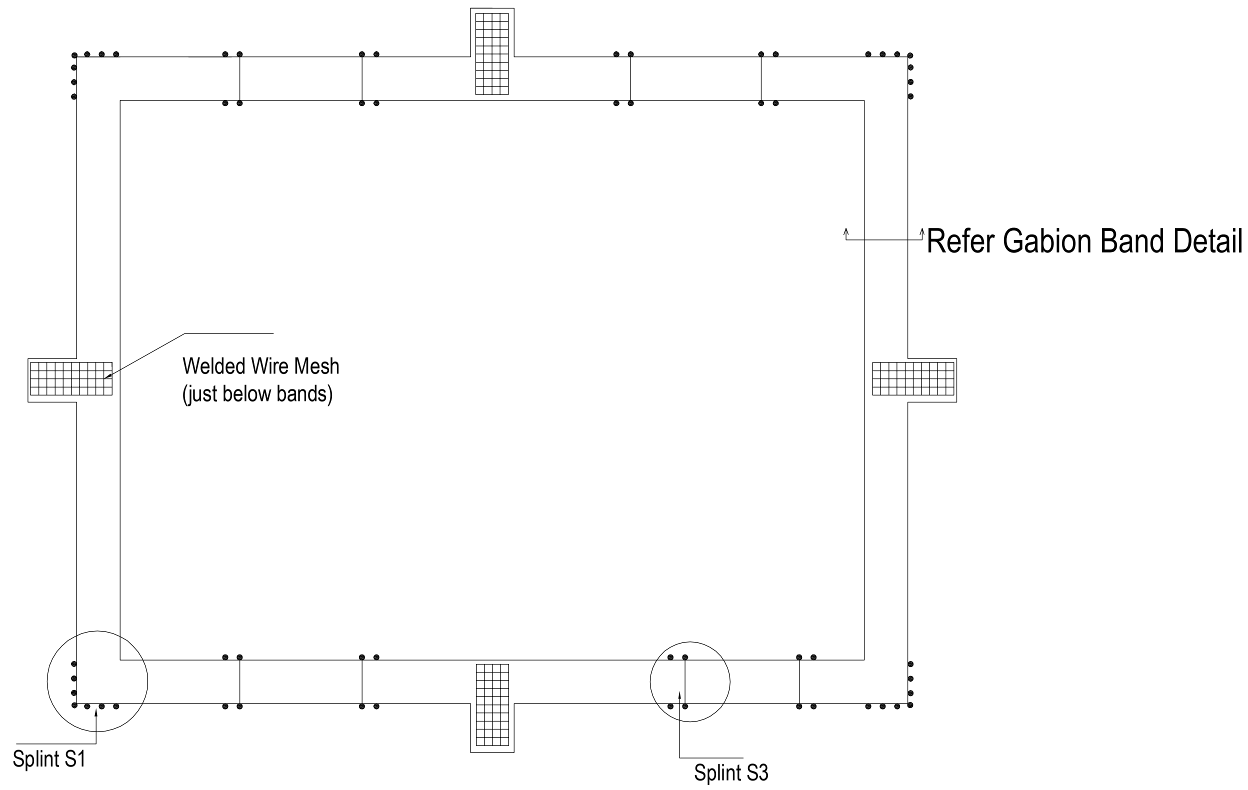
Proposed Two-Third Scale Drawings of Semi-dressed Stone Masonry with Gabion mesh/Geogrid bands and Wire Containment

Type 2

Asian Development Bank



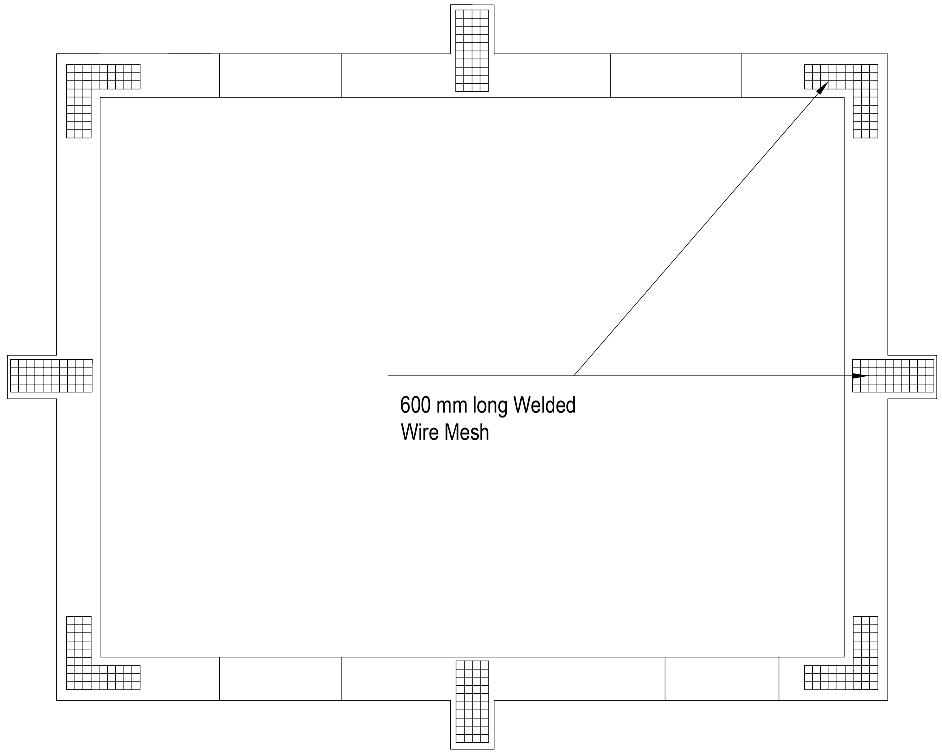
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (Two Third Scale Drawings) Type# 2	FLOOR PLAN	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 01



- Containment wires not shown for clarity.
- Plinth band not provided.
- Wires shown for splints are representative only.

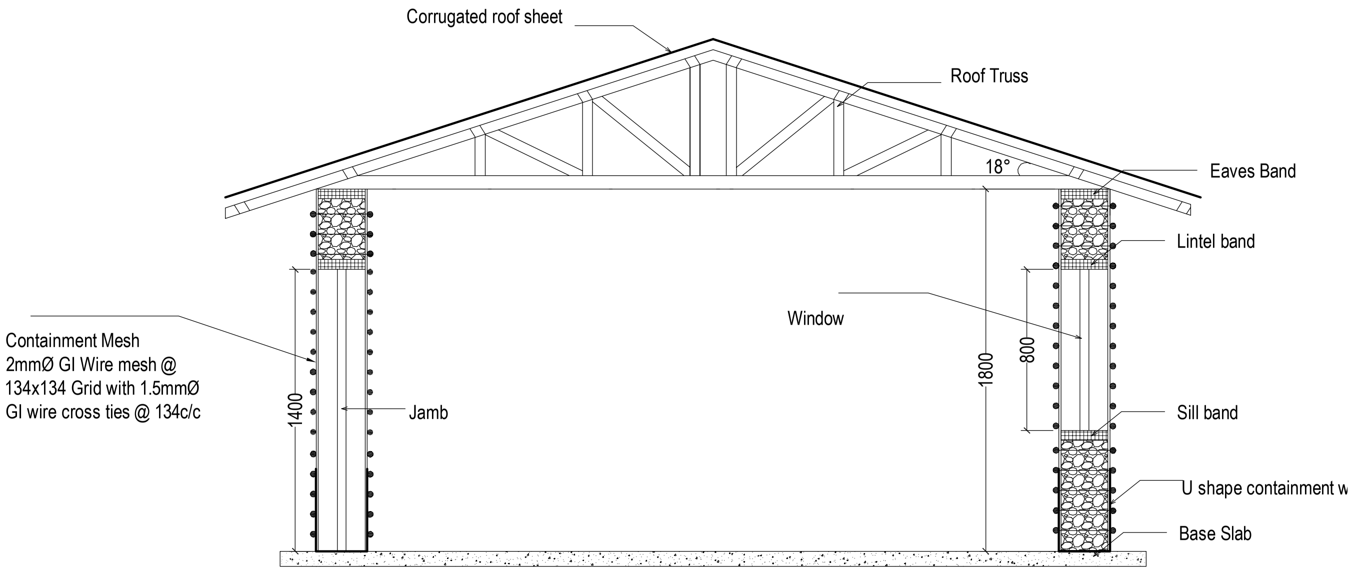
- Provide Buttress Stitches at
  > Plinth, Sill, Lintel and Eaves Level.
  > Between Plinth and Sill.
  > Between Lintel and Eaves Level.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (Two Third Scale Drawings) Type# 2	Band, Vertical wires at Wall-Junctions Jambs and Buttress Stitches	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 02



- Welded Wire Mesh (WWM) placed midway between
    1. DPC and Sill Level, and
    2. Sill and Lintel Level.
- WWM embedded in mortar layer.
- Splints S1 and S3 not shown for clarity.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (Two Third Scale Drawings) Type# 2	Stitch Detail	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 03

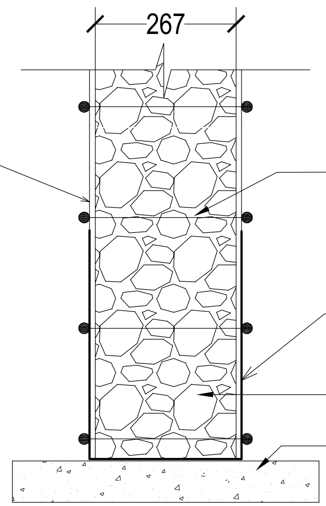


Note:

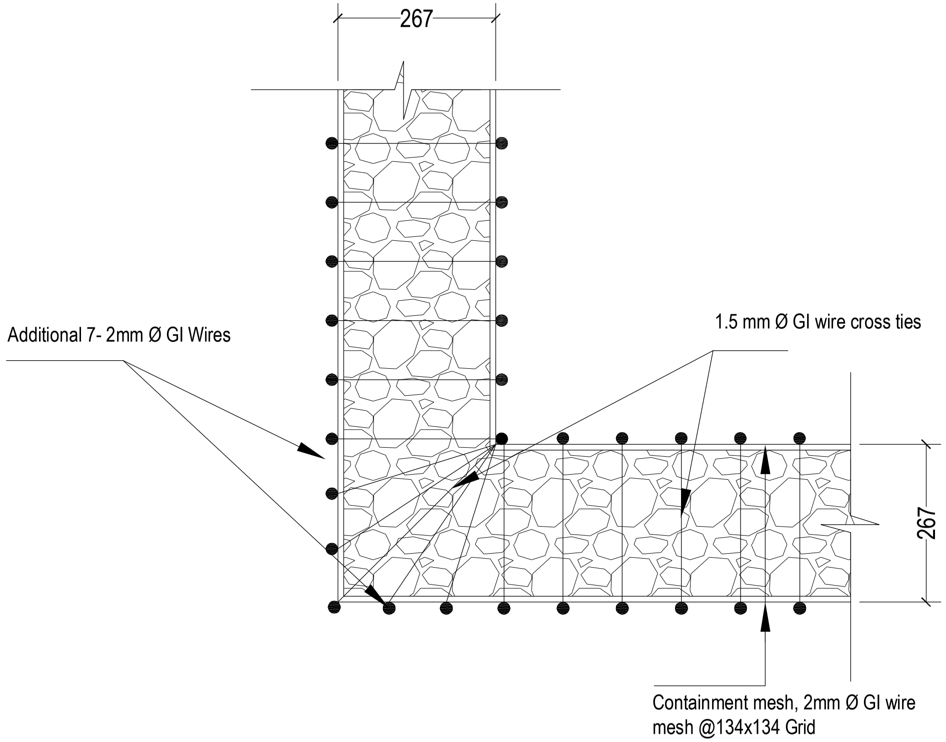
1. At eaves band, the vertical wires from both the interior and exterior faces connects at top of the eaves band and hence intertwined.
2. Containment Wires in the shape of U is placed below the first course and then it is intertwined with the vertical containment. U shape is shown as bold lines in the drawing.

Levels	
Ridge Level	+2693 mm
CeilingLevel	+1800 mm
Lintel Level	+1400 mm
Sill Level	+600 mm
Base Slab	+00 mm

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (Two Third Scale Drawings) Type# 2	Structural Section	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 04



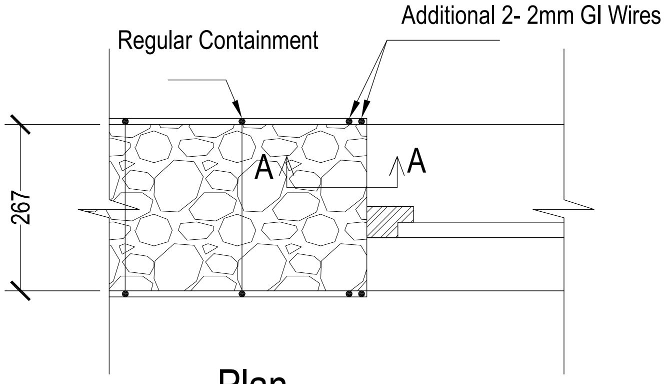
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (Two Third Scale Drawings) Type# 2	Wall Section Detail	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 05



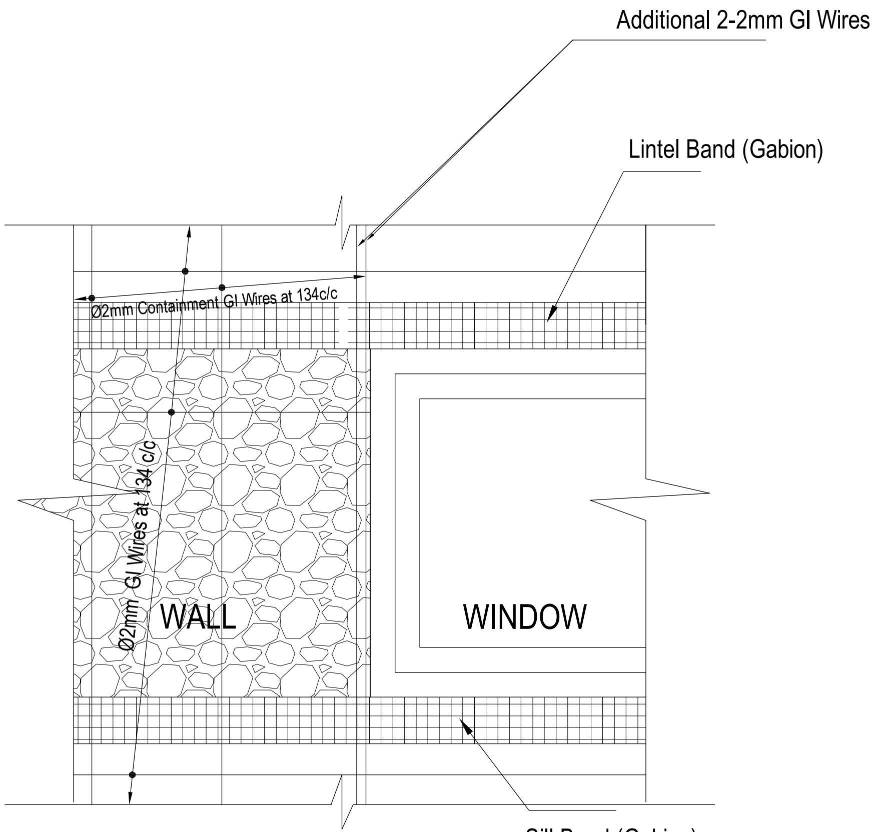
Corner Splint S1

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (Two Third Scale Drawings) Type# 2	Corner Splint S1 Detail	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 06

Note: The scaling is based on
bar diameter rather than area.



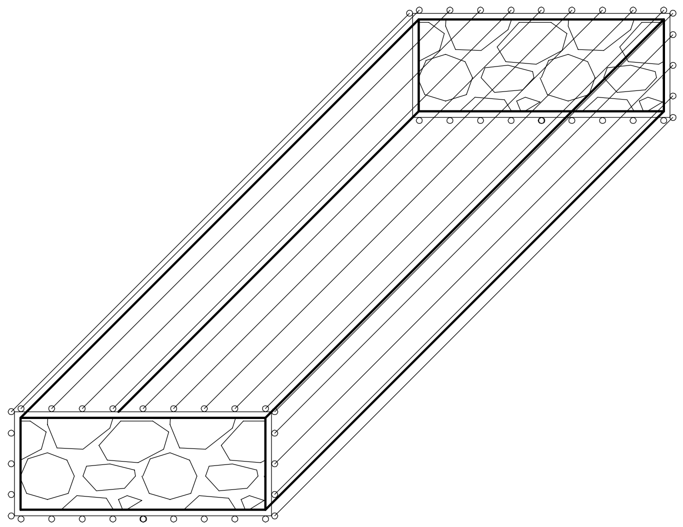
Plan



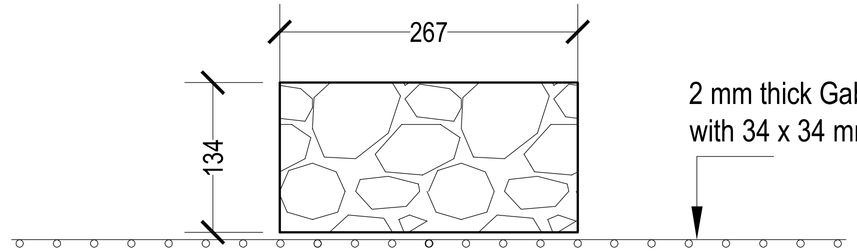
Section at A-A

Jamb Splint S3

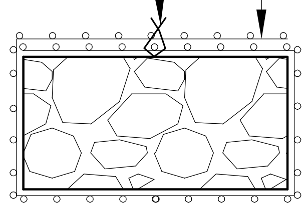
Consultant Name: University of Engineering and Technology Peshawar.	Client Name: ADB Asian Development Bank	Design Type: Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (Two Third Scale Drawings) Type# 2	TITLE: Jamb Splint S3 Detail	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad; Drafted by: Engr. Attaur Rahman	Date: September 2018; Scale: Read As Shown; Dwg. No. 07



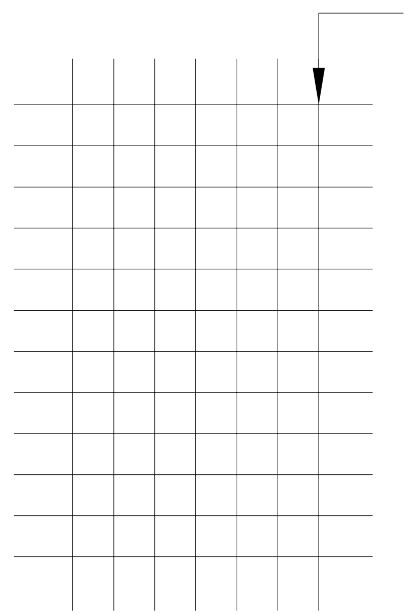
3D view of Gabian Band (Cross wires are not shown for clarity at mid sections)



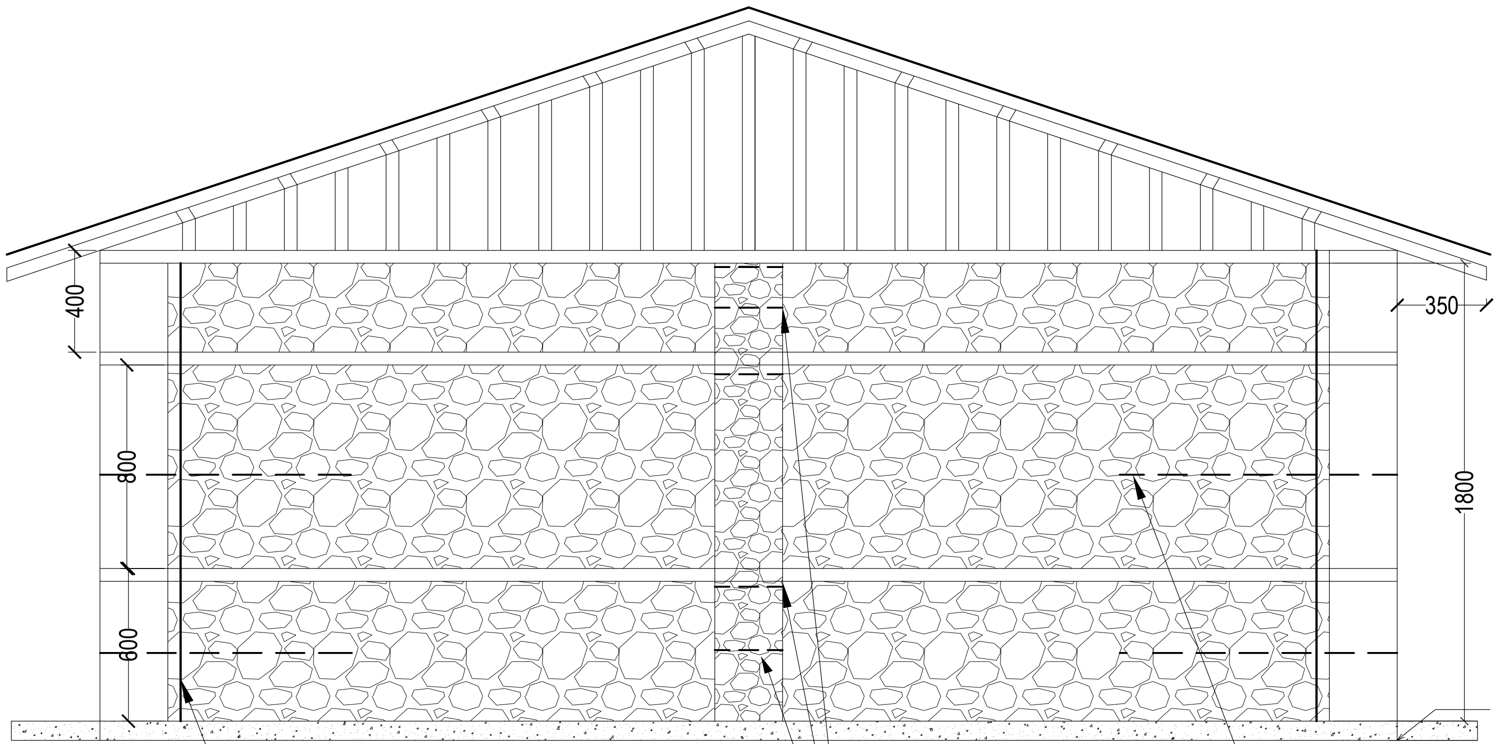
X-Section of Wall with Unwraped Gabian Mesh



X-Section of Wall with wraped Gabian Mesh

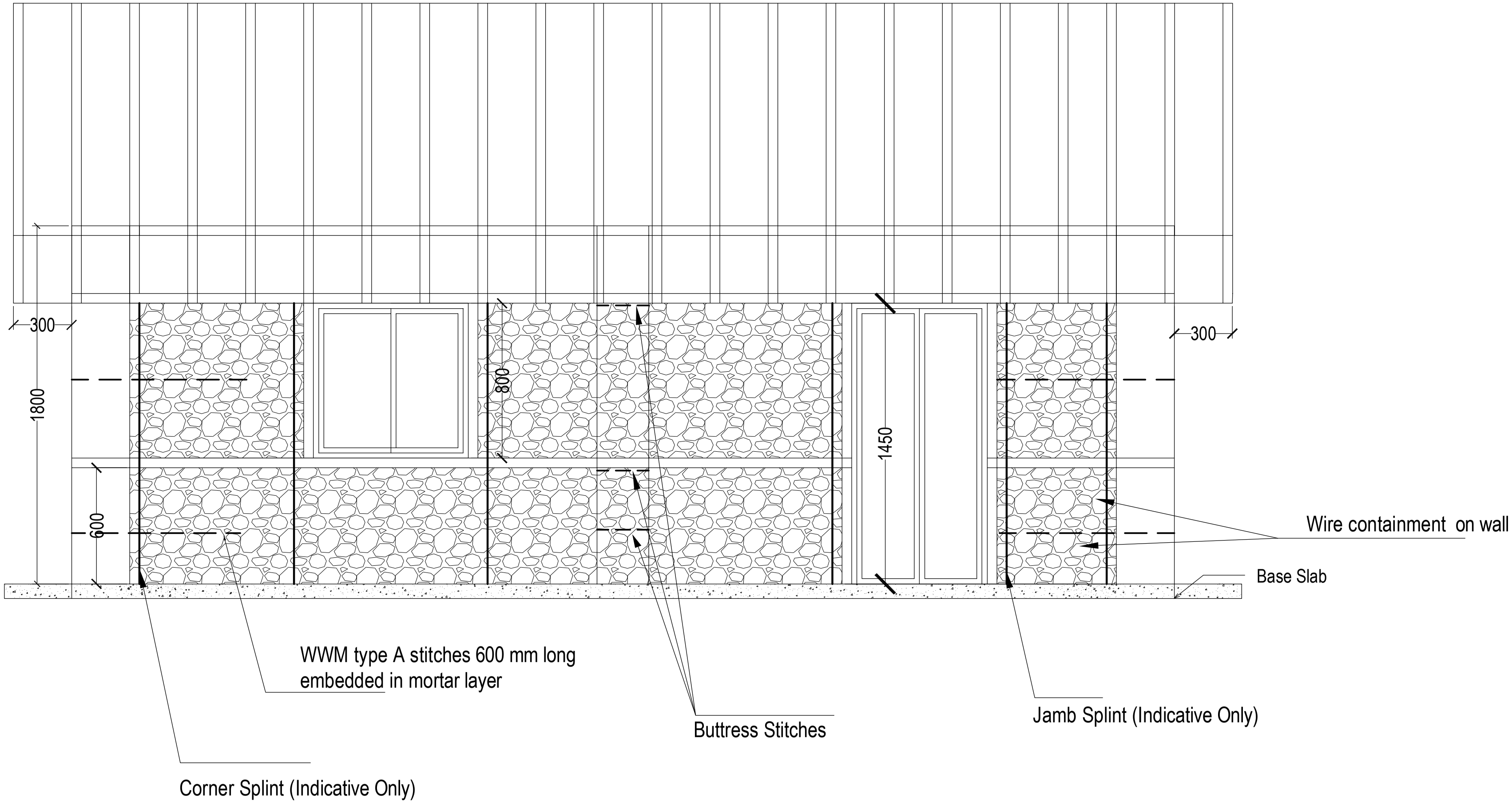


Consultant Name: University of Engineering and Technology Peshawar.	Client Name: Asian Development Bank	Design Type: Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (Two Third Scale Drawings) Type# 2	TITLE: Sill Band Detail, Lintel Band Detail, Eaves Band Detail	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad	Date: September 2018
				Drafted by: Engr. Attaur Rahman	Scale: Read As Shown
					Dwg. No. 08



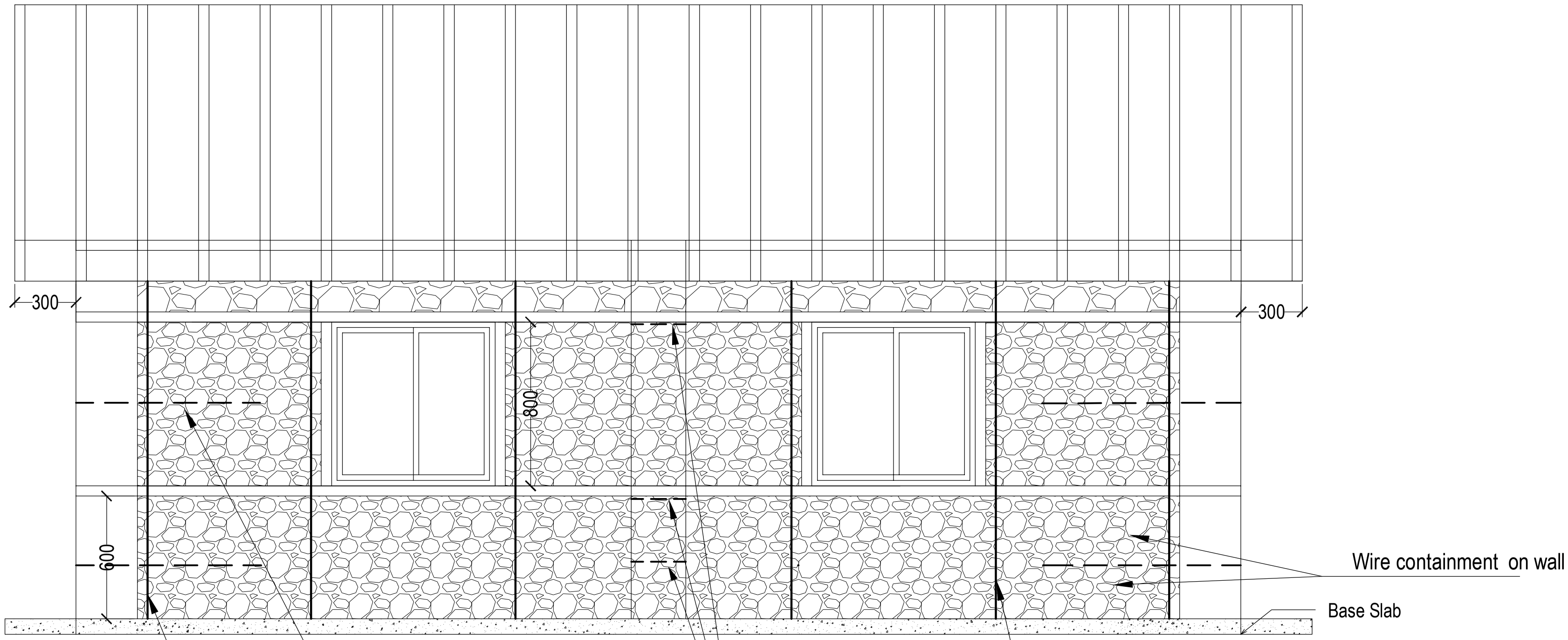
Side Elevation

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (Two Third Scale Drawings) Type# 2	Side Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 09



Front Elevation

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (Two Third Scale Drawings) Type# 2	Front Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 10



Back Elevation

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (Two Third Scale Drawings) Type# 2	Back Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 11

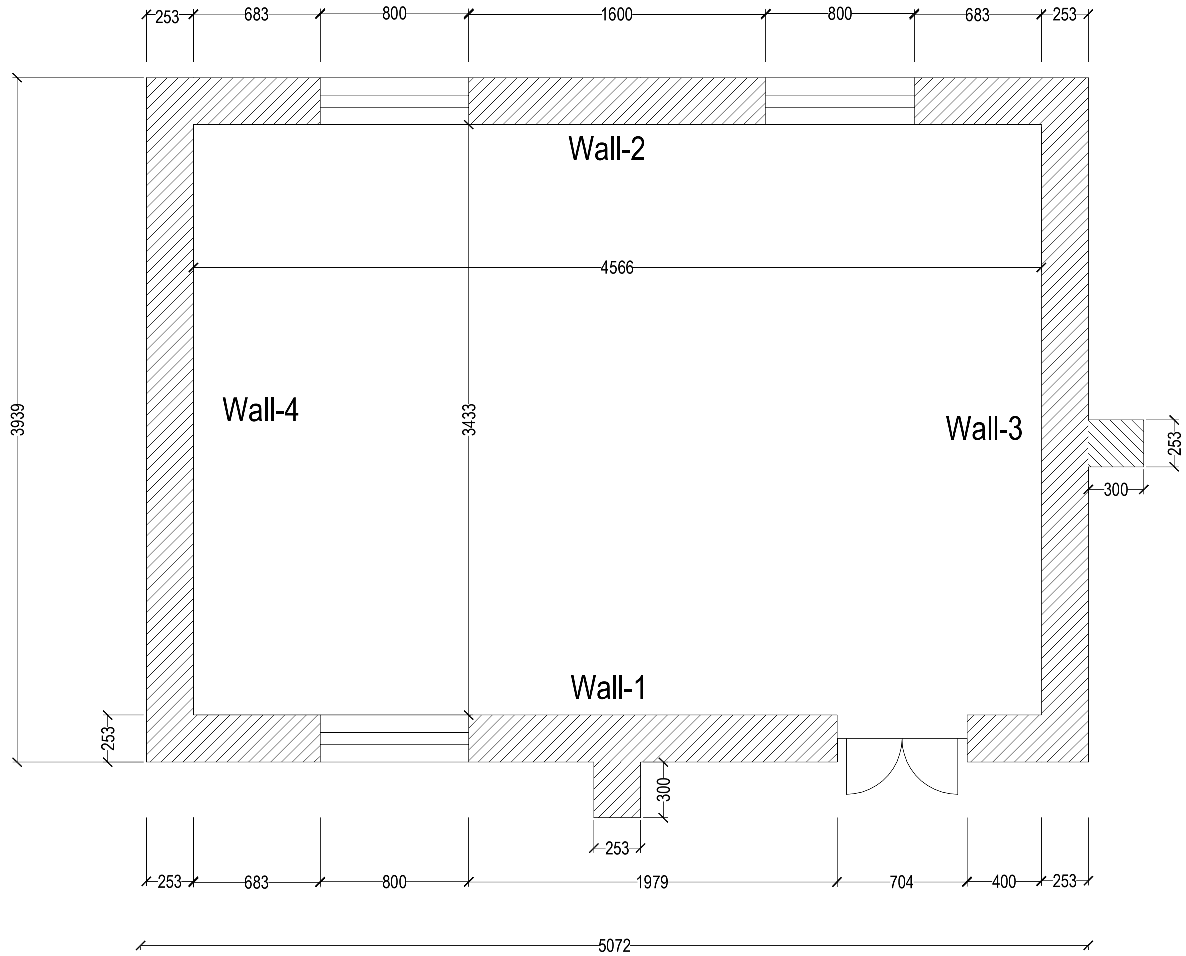
Appendix C3 – School Design Detailed Drawings-2/3rd Scale Model (Type Design 3)

Proposed Two Third Drawings of Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands

Type 3

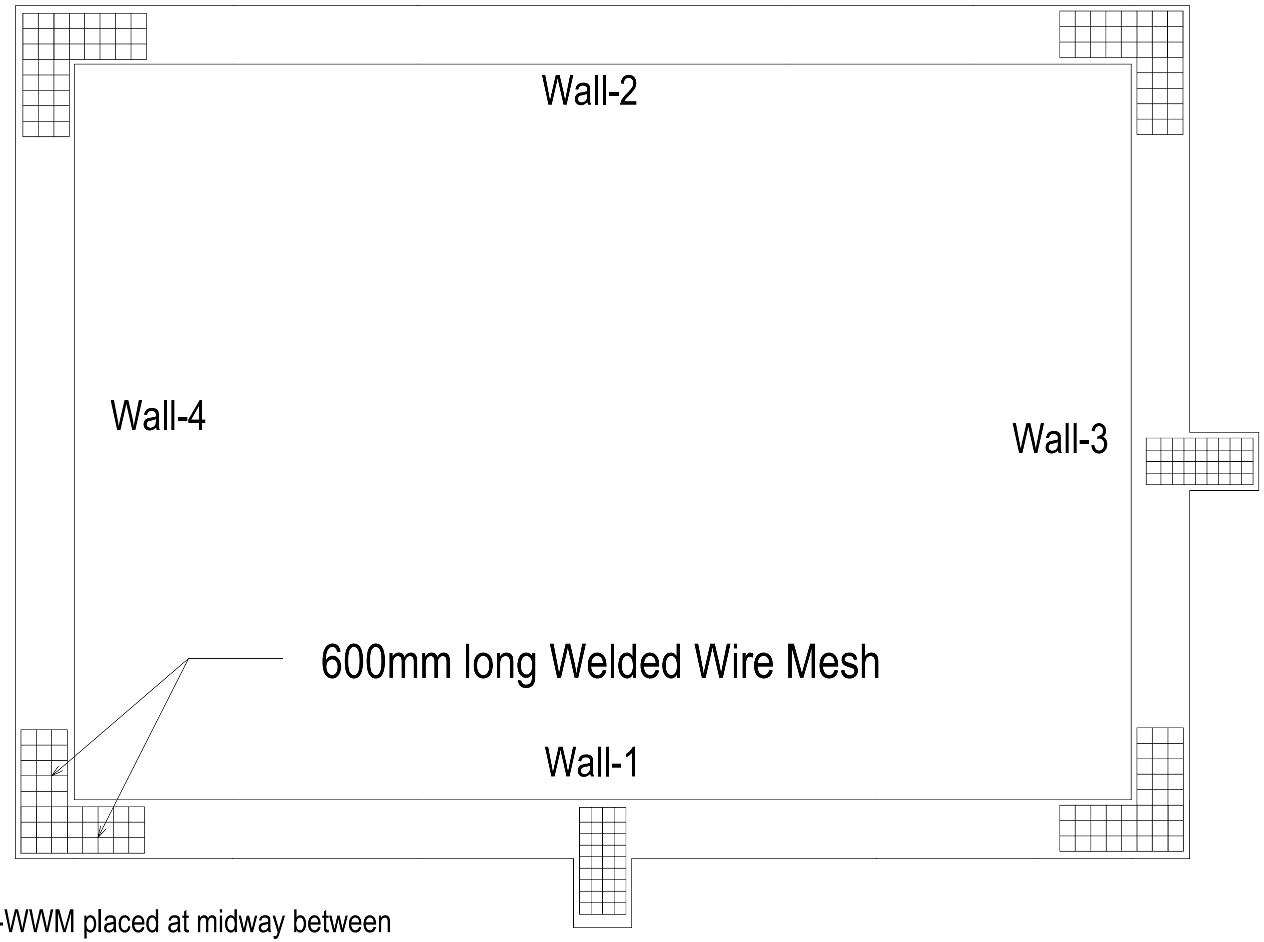
ADB

Asian Development Bank



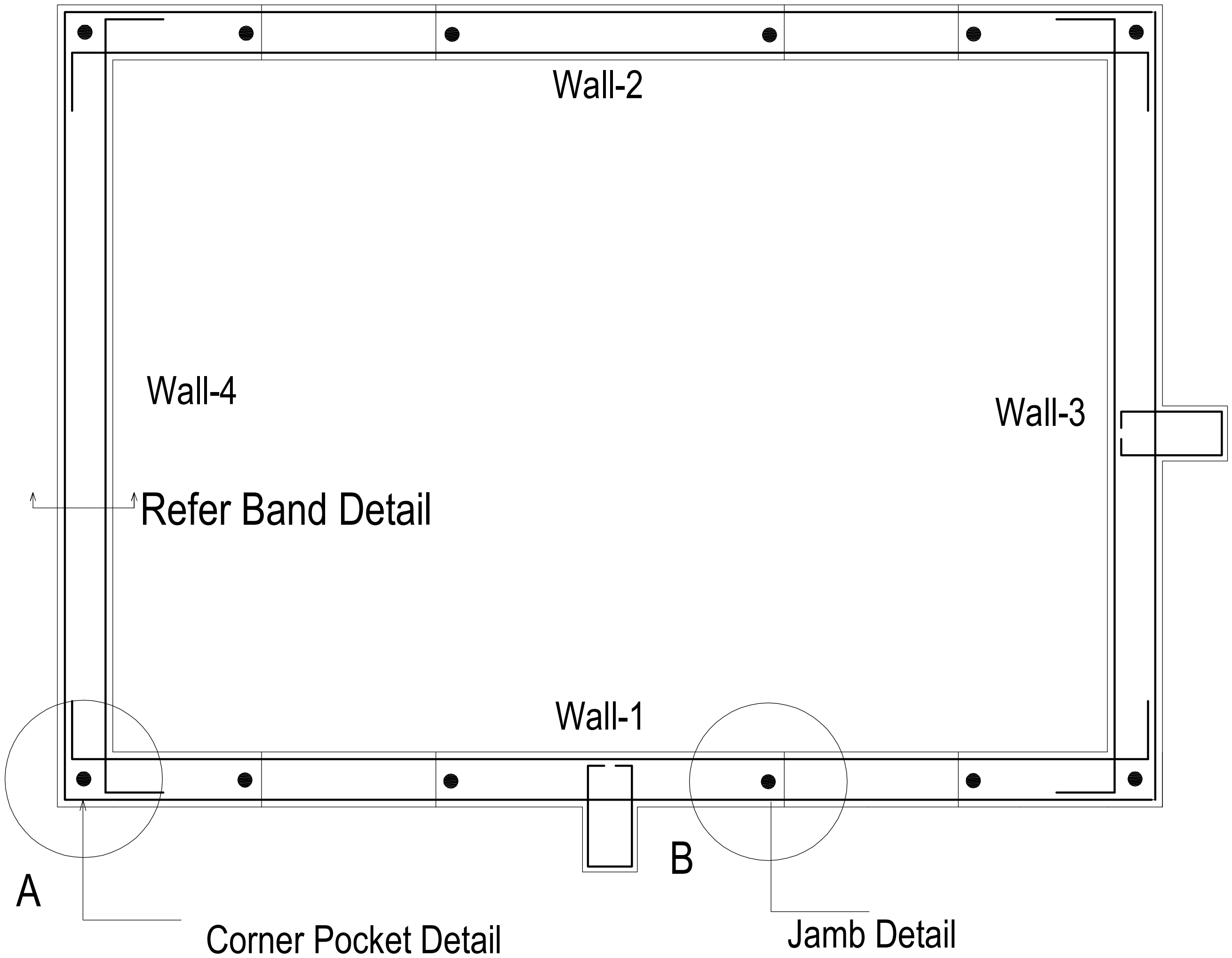
Floor Plan

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Drawings) Type# 3	FLOOR PLAN	Dr. Qaisar Ali, Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 01



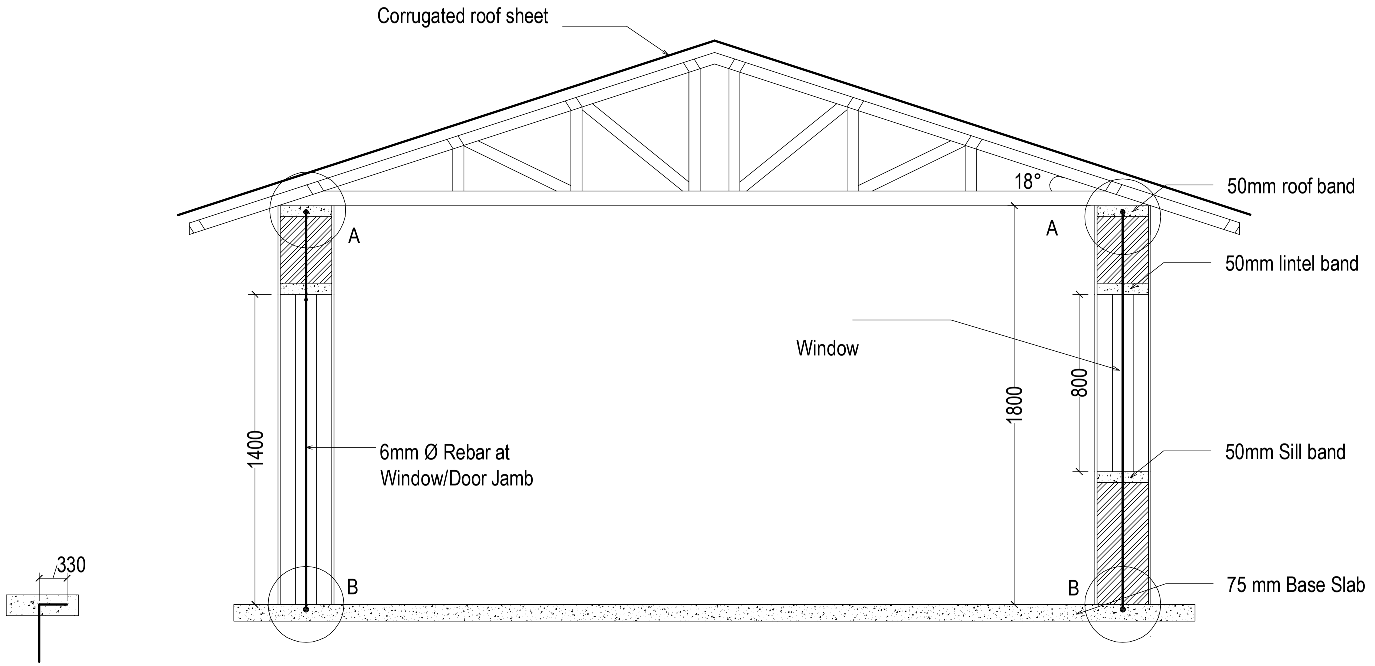
-WWM placed at midway between
> DPC and Sill Level
> Sill and Lintel Level
-WWM embedded in mortar layer

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Drawings) Type# 3	Stitch Detail	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 02



Stirrups are not shown for Clarity.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Drawings) Type# 3	Jamb plan at Plinth, Sill, Lintel and Eaves Level	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 03



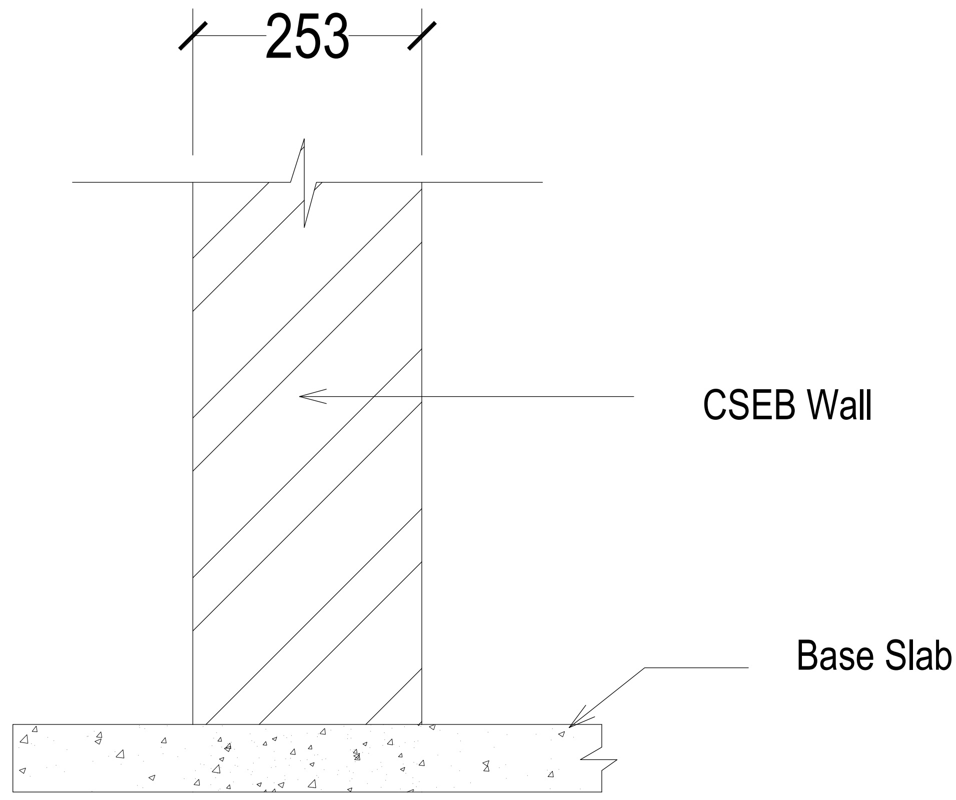
'A'
Connection of Jamb rebar with Ceiling Band

'B'
Jamb rebars were connected to the base slab using epoxy.

Structural Section

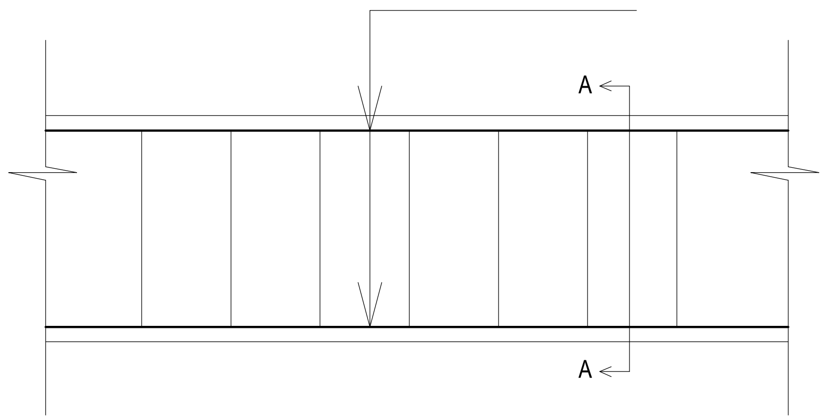
Levels	
Ridge Level	+2593 mm
Floor Level	+1800 mm
Lintel Level	+1400 mm
Sill Level	+600 mm
Base Pad	+00 mm

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Drawings) Type# 3	Structural Section	Dr. Qaisar Ali Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: September 2018 Scale: Read As Shown Dwg. No. 04

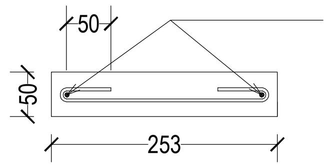


Wall Section

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Drawings) Type# 3	Wall Section	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 05



Typical Band Detail

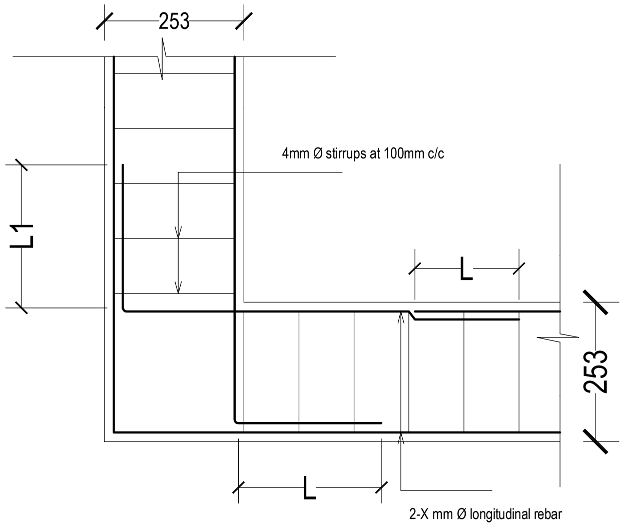


Section at A-A
Band Detail

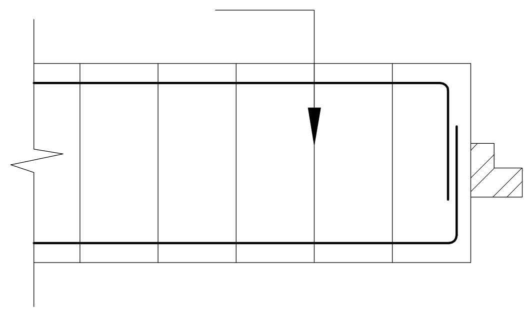
Note: The scaling is based on bar diameter rather than area.

Rebar Size in Bands	
Band Level	Rebar Diameter (X)
Plinth Level	7 mm
Sill Band	7 mm
Lintel Band	8 mm
Eaves	8 mm

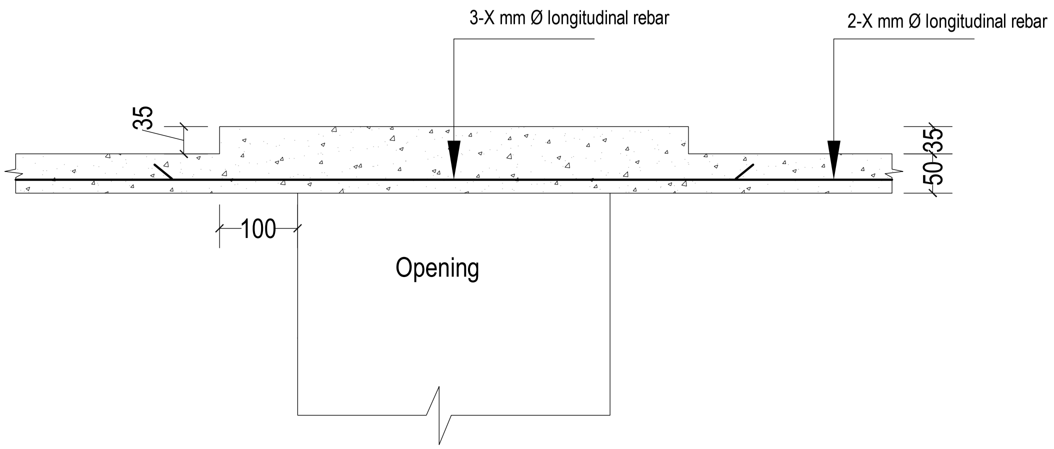
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Drawings) Type# 3	Typical Band Plan	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 06



Band Detail at corner junction



Sill Level Band at Door



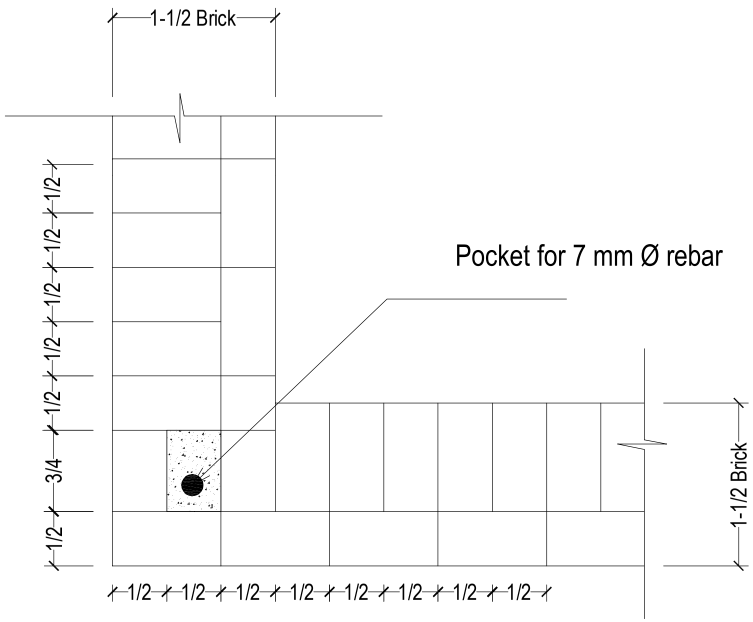
Lintel Band above Openings

Rebar Diameter	Lap Length, L	Hook Length, L1
7 mm	440mm	150 mm
8 mm	600mm	230 mm

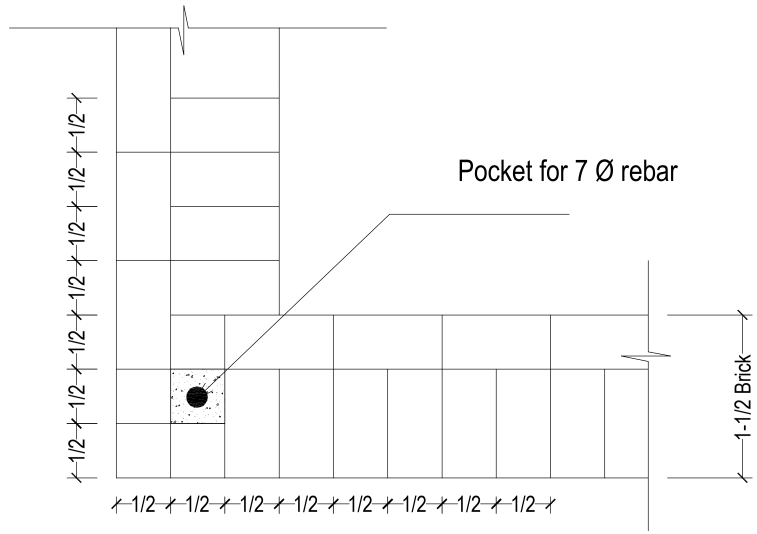
Rebar Size in Bands

Band Level	Rebar Diameter (X)
Plinth Level	7 mm
Sill Band	7 mm
Lintel Band	8 mm
Eaves	8mm

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Drawings) Type# 3	Band Detail at Corner Junction Lintel Band Detail above Openings	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 07

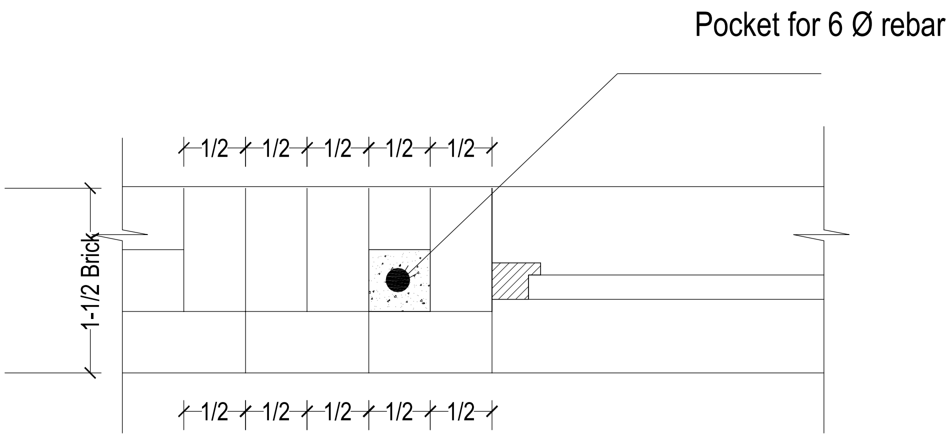


First Layer course
(Corner Junction)

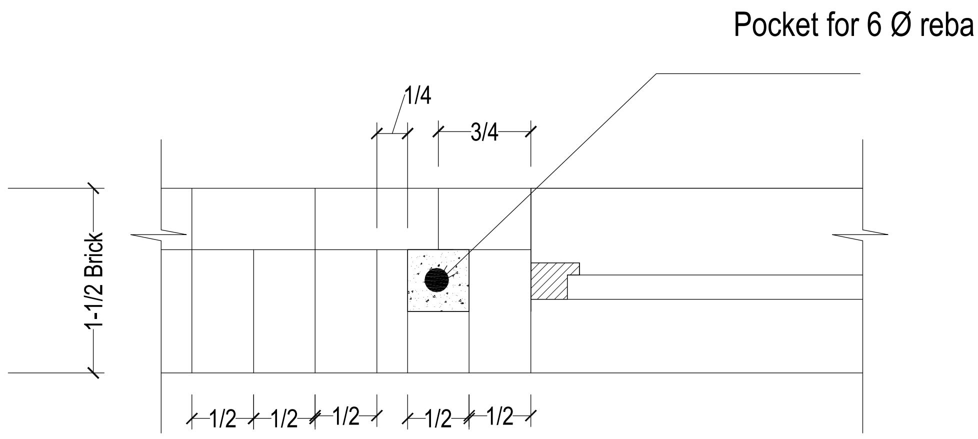


Second Layer course
(Corner Junction)

Consultant Name: University of Engineering and Technology Peshawar.	Client Name: ADB Asian Development Bank	Design Type: Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Drawings) Type# 3	TITLE Corner Junction Courses	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: September 2018 Scale: Read As Shown Dwg. No. 08

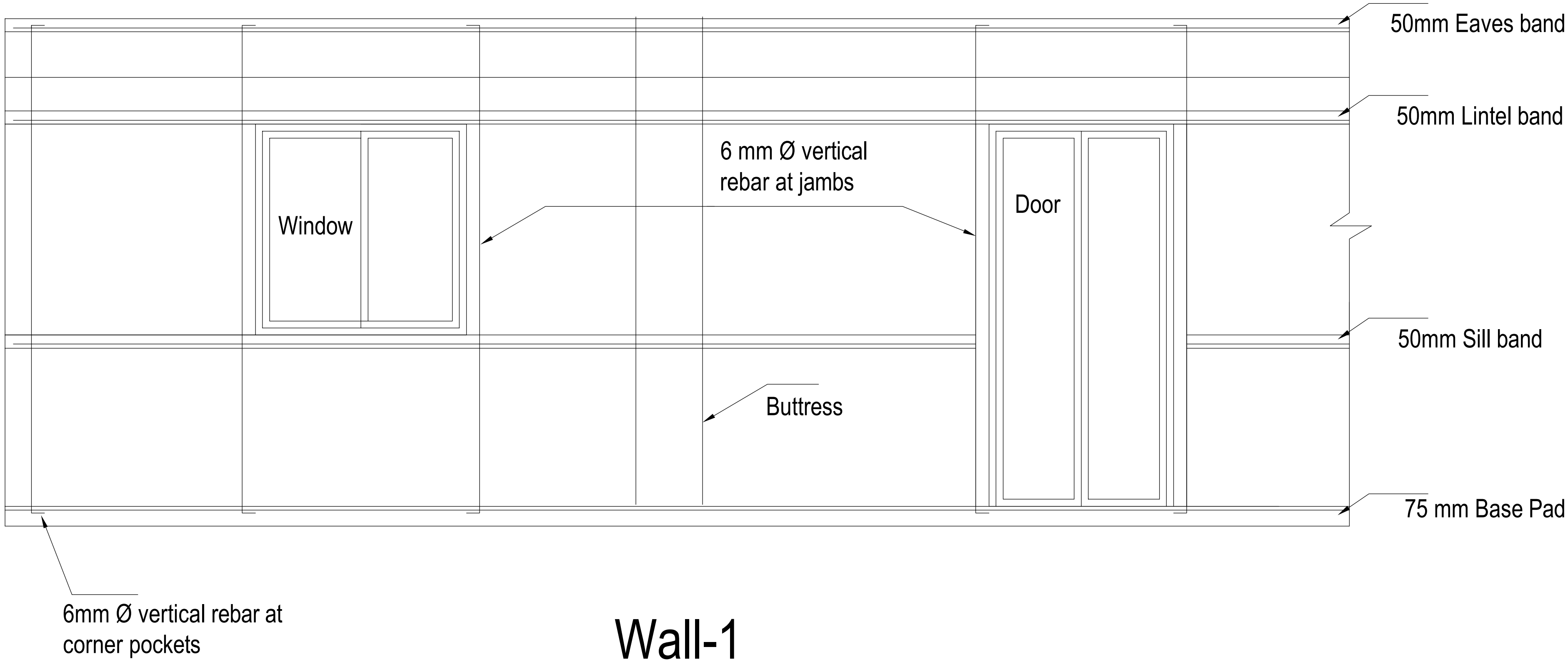


First Layer course
(Door/Window Jamb)



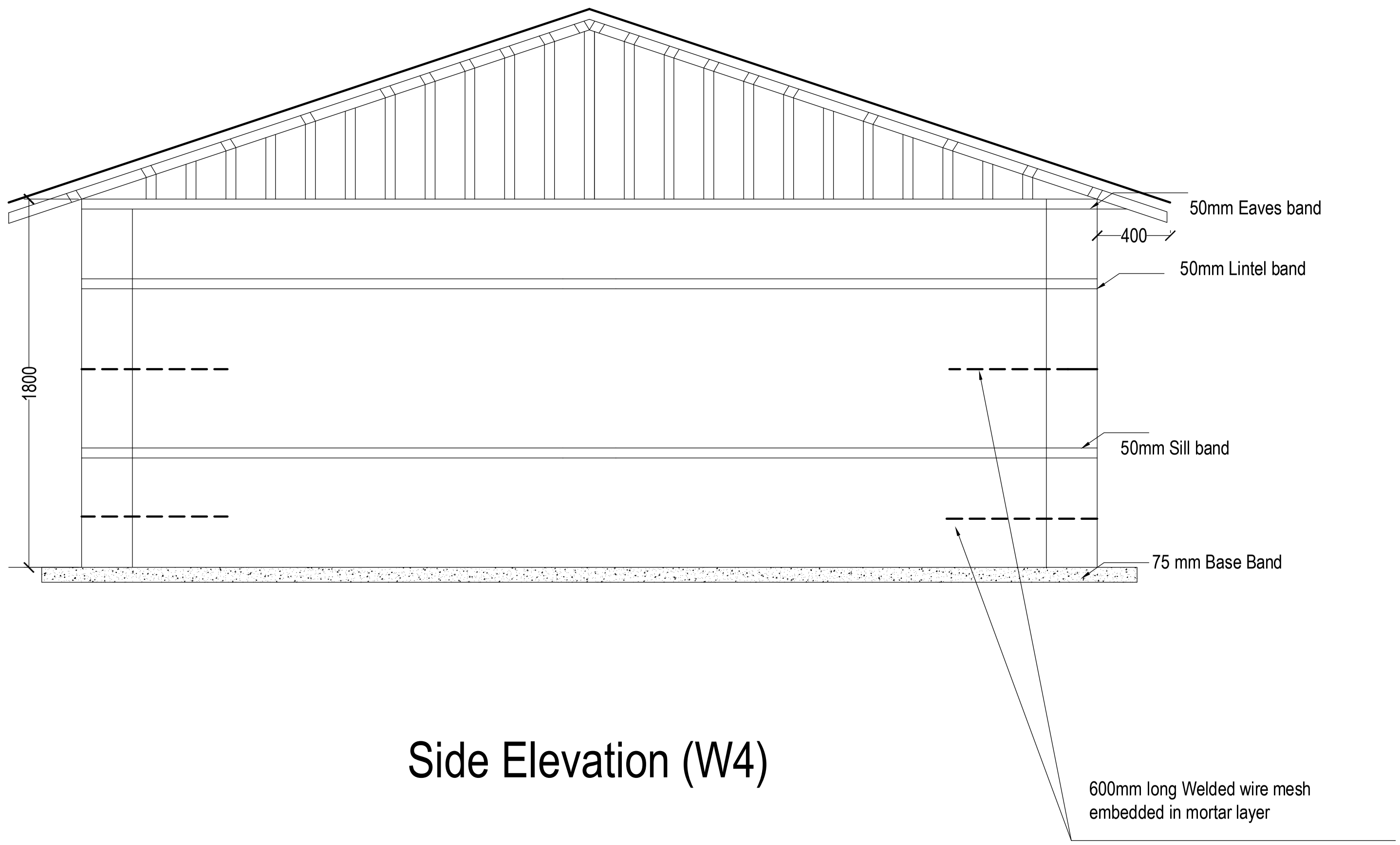
Second Layer course
(Door/Windows Jamb)

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Drawings) Type# 3	Courses at Jamb (Window/Door)	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 09



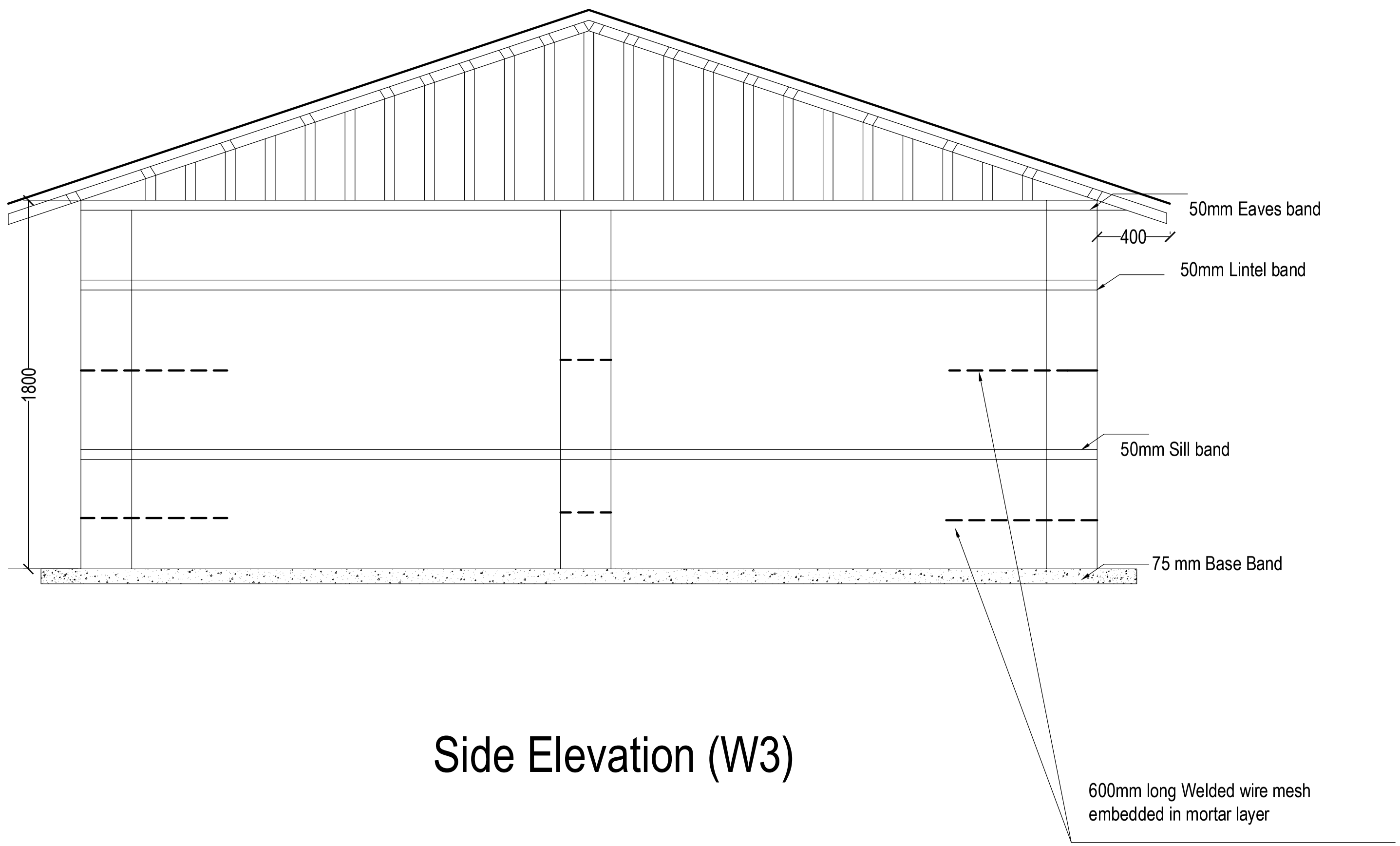
Wall-1

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Drawings) Type# 3	Vertical Bars at Jamb Detail	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 10



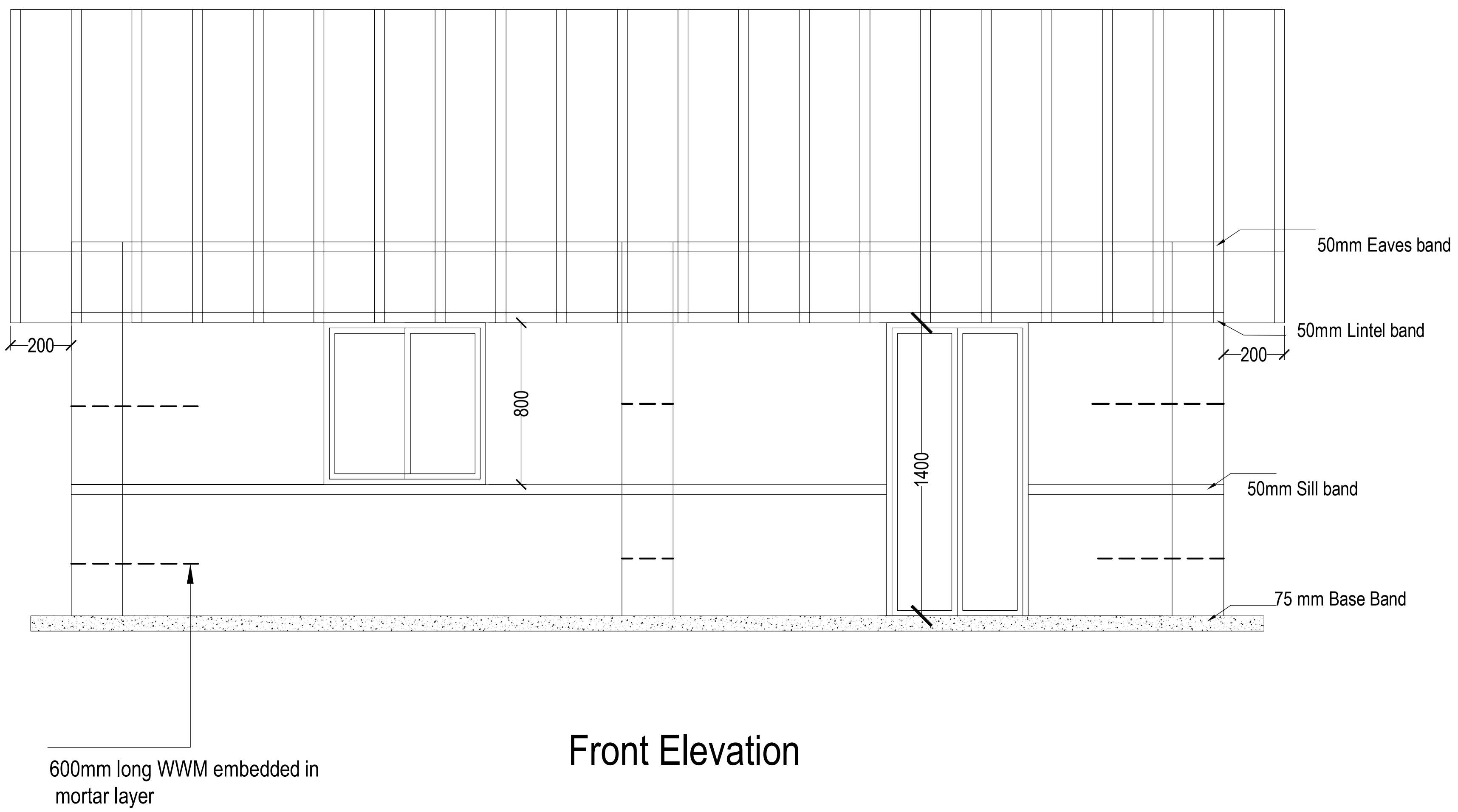
Side Elevation (W4)

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Drawings) Type# 3	Side Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 11



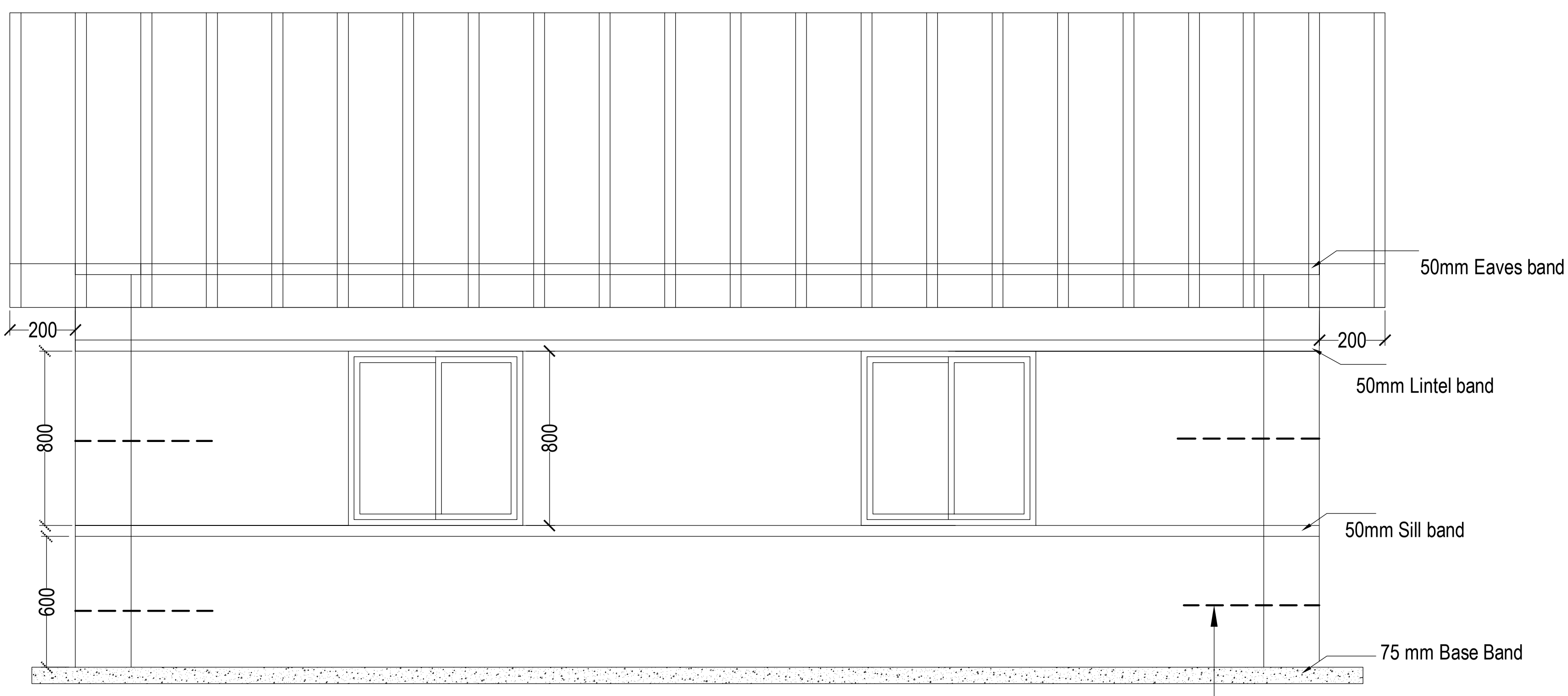
Side Elevation (W3)

Consultant Name: University of Engineering and Technology Peshawar.	Client Name: ADB Asian Development Bank	Design Type: Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Drawings) Type# 3	TITLE Side Elevation	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: September 2018 Scale: Read As Shown Dwg. No. 12



Front Elevation

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Drawings) Type# 3	Front Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 13



Back Elevation

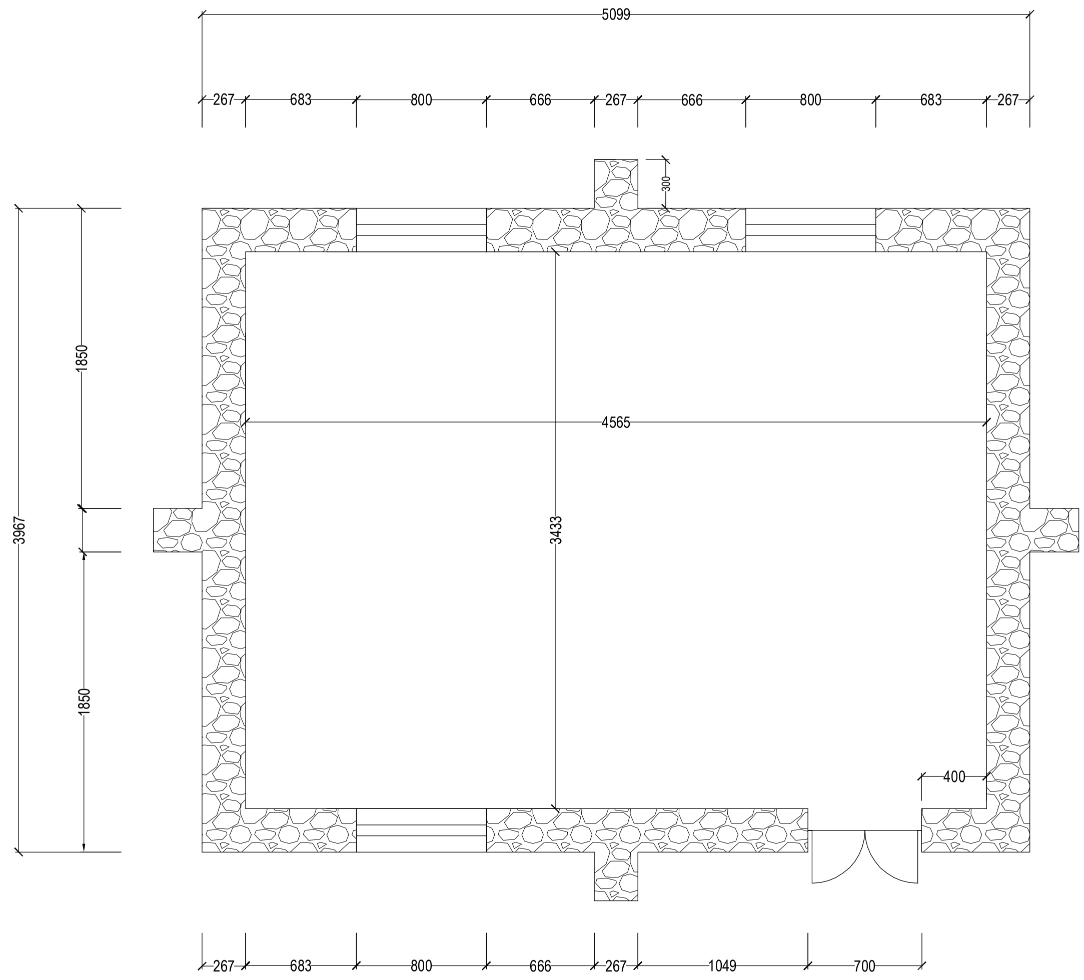
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Drawings) Type# 3	Back Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 14

Appendix C4 – School Design Detailed Drawings-2/3rd Scale Model (Type Design 4)

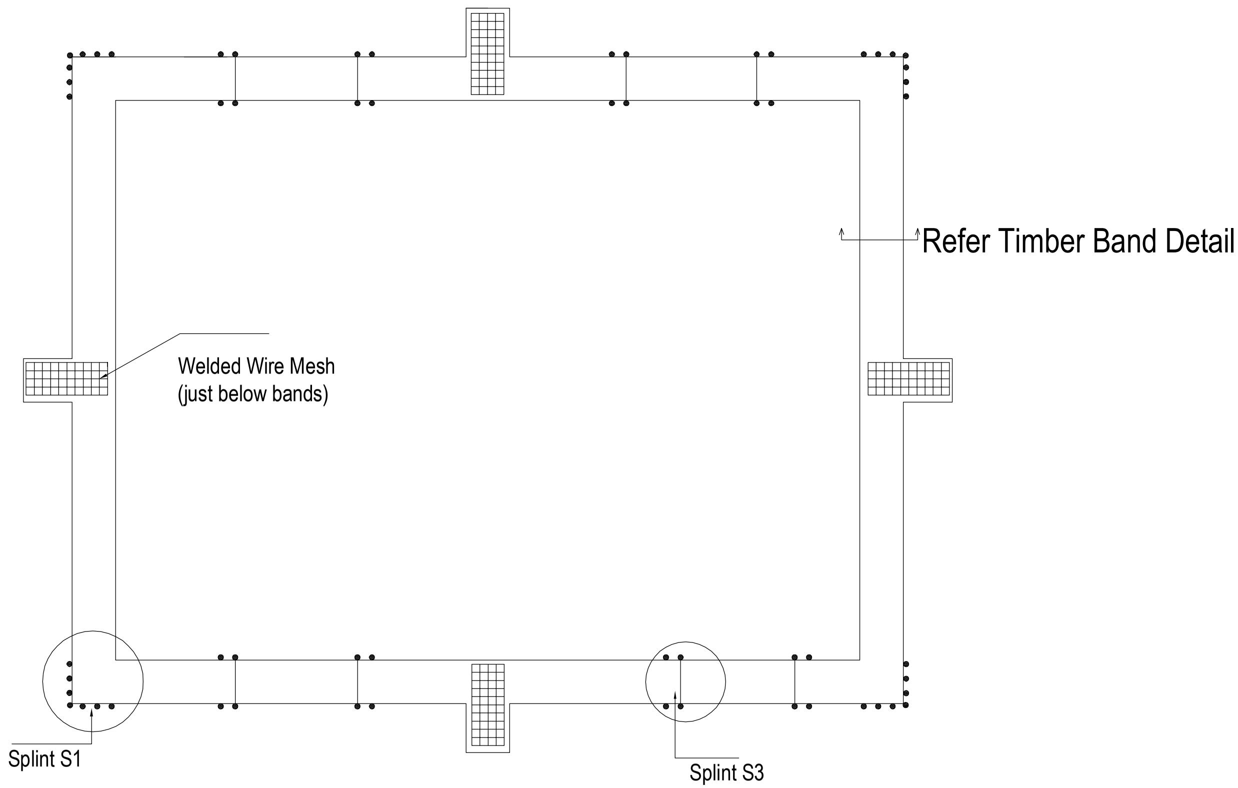
Proposed Two-Third Scale Drawings of Semi-Dressed Stone Masonry with Timber Bands and Wire Containment

Type 4

Asian Development Bank



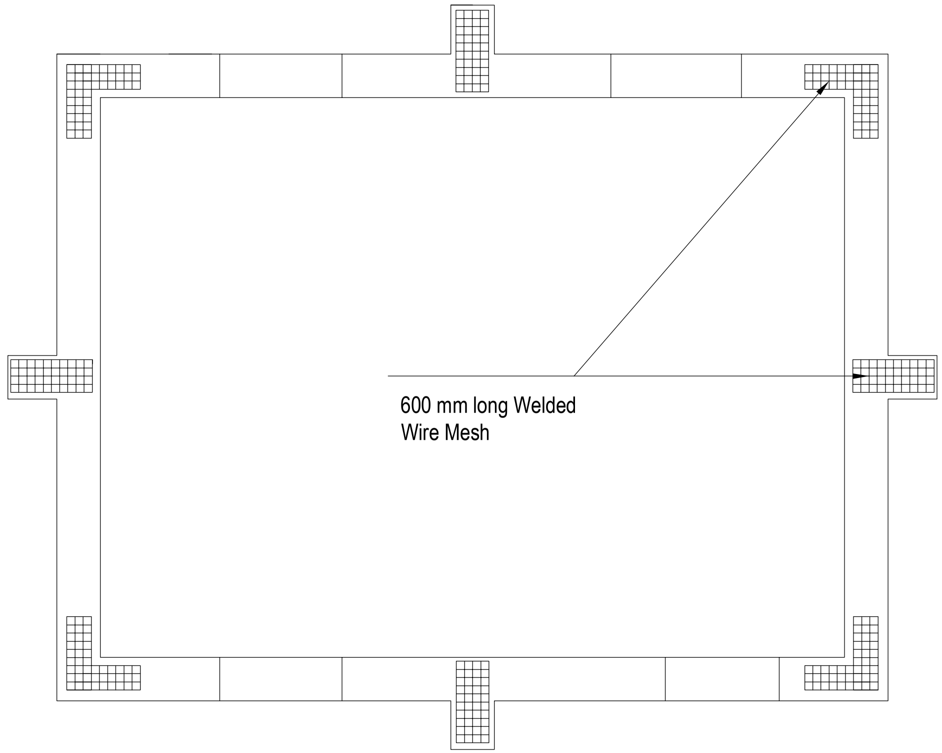
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	ADB Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (Two Third Scale Drawings) Type# 4	FLOOR PLAN	Dr. Qaisar Ali, Dr. Naveed Ahmad	Date: September 2018
				Drafted by: Engr. Attaur Rahman	Scale: Read As Shown
					Dwg. No. 01



- Containment wires not shown for clarity.
- Plinth band not provided.
- Wires shown for splints are representative only.

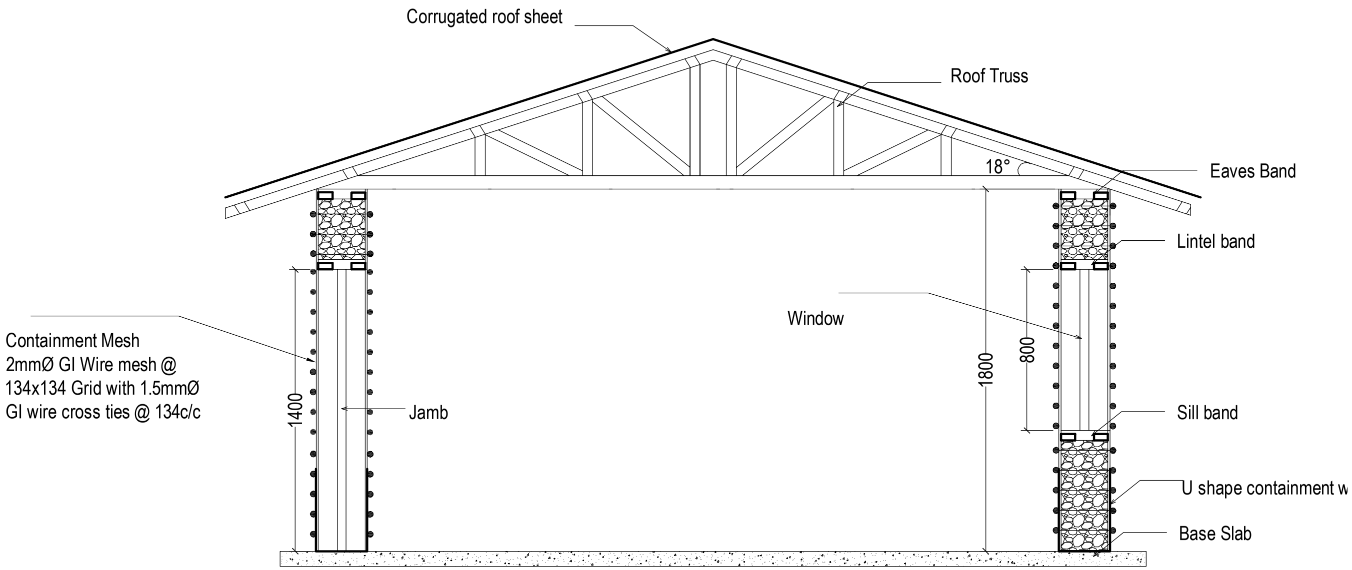
- Provide Buttress Stitches at
  > Plinth, Sill, Lintel and Eaves Level.
  > Between Plinth and Sill.
  > Between Lintel and Eaves Level.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	ADB Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (Two Third Scale Drawings) Type# 4	Vertical wires at Wall Junctions Jambs and Butresses Stitches	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 02



- Welded Wire Mesh (WWM) placed midway between
    1. DPC and Sill Level, and
    2. Sill and Lintel Level.
- WWM embedded in mortar layer.
- Splints S1 and S3 not shown for clarity.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (Two Third Scale Drawings) Type# 4	Stitch Detail	Dr. Qaisar Ali Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: September 2018 Scale: Read As Shown Dwg. No. 03

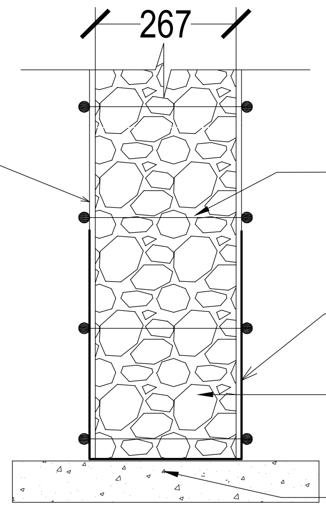


Note:

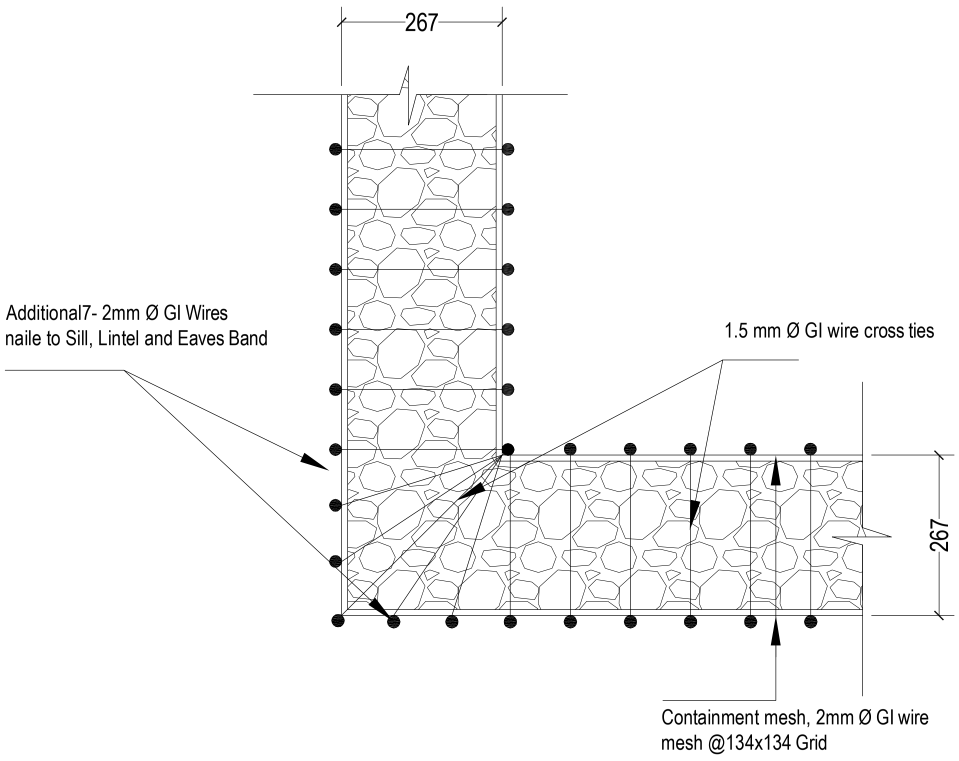
1. The vertical wires are connected to sill, lintel and eaves band by wrapping it around a nail and then hammered.
2. At eaves band, the vertical wires from both the interior and exterior faces connects at top of the eaves band and hence intertwined.
3. Containment Wires in the shape of U is placed below the first course and then it is intertwined with the vertical containment. U shape is shown as bold lines in the drawing.

Levels	
Ridge Level	+2693 mm
CeilingLevel	+1800 mm
Lintel Level	+1400 mm
Sill Level	+600 mm
Base Slab	+00 mm

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (Two Third Scale Drawings) Type# 4	Structural Section	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 04



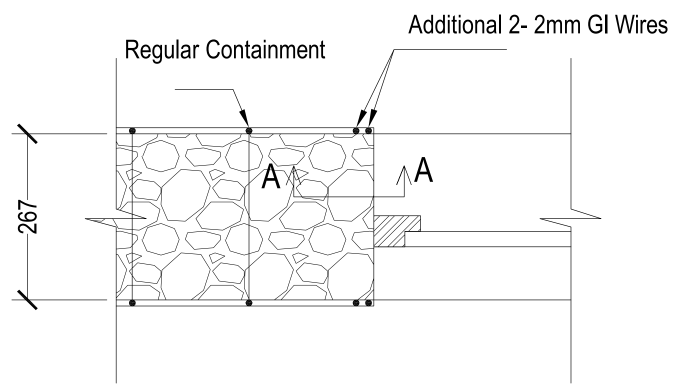
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (Two Third Scale Drawings) Type# 4	Wall Section Detail	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 05

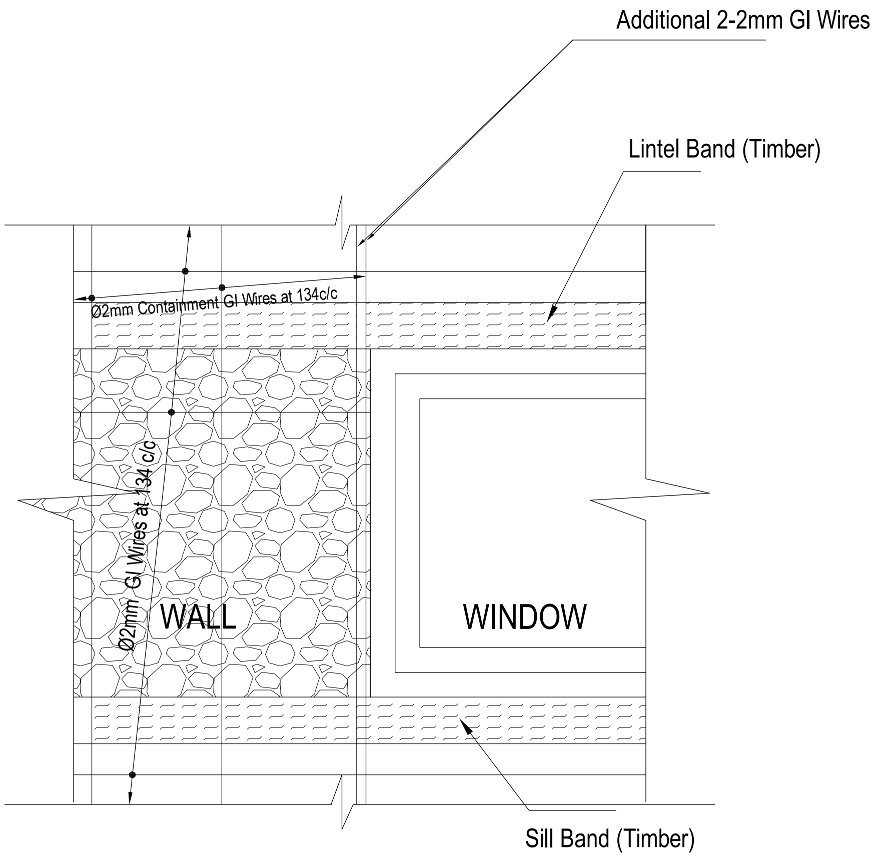


Corner Splint S1

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (Two Third Scale Drawings) Type# 4	Corner Splint S1 Detail	Dr. Qaisar Ali, Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 06

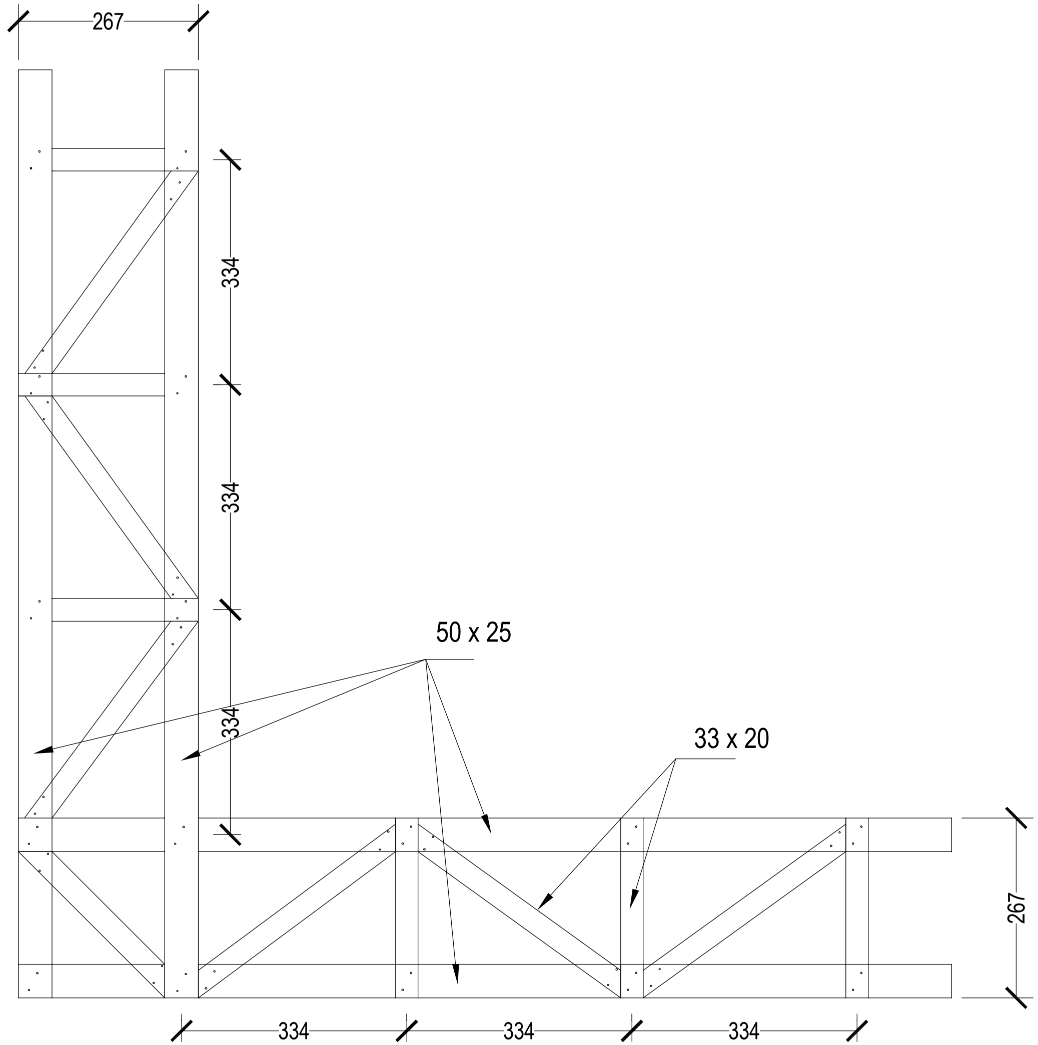
Note: The scaling is based on
bar diameter rather than area.





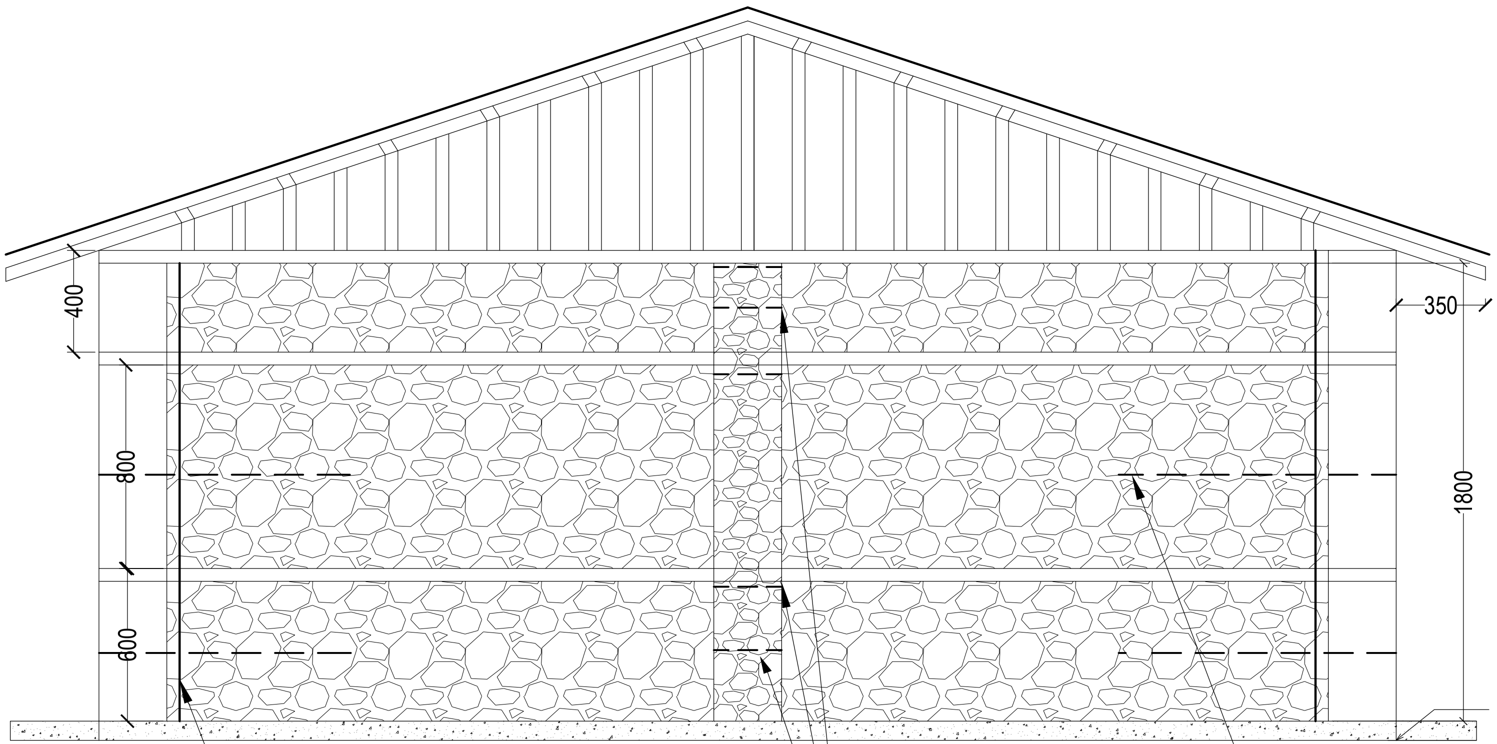
Section at A-A

Consultant Name: University of Engineering and Technology Peshawar.	Client Name: Asian Development Bank	Design Type: Semidressed Stone Masonry with Timber Bands and wire containment (Two Third Scale Drawings) Type# 4	TITLE: Jamb Splint S3 Detail	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad	Date: September 2018
					Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 07



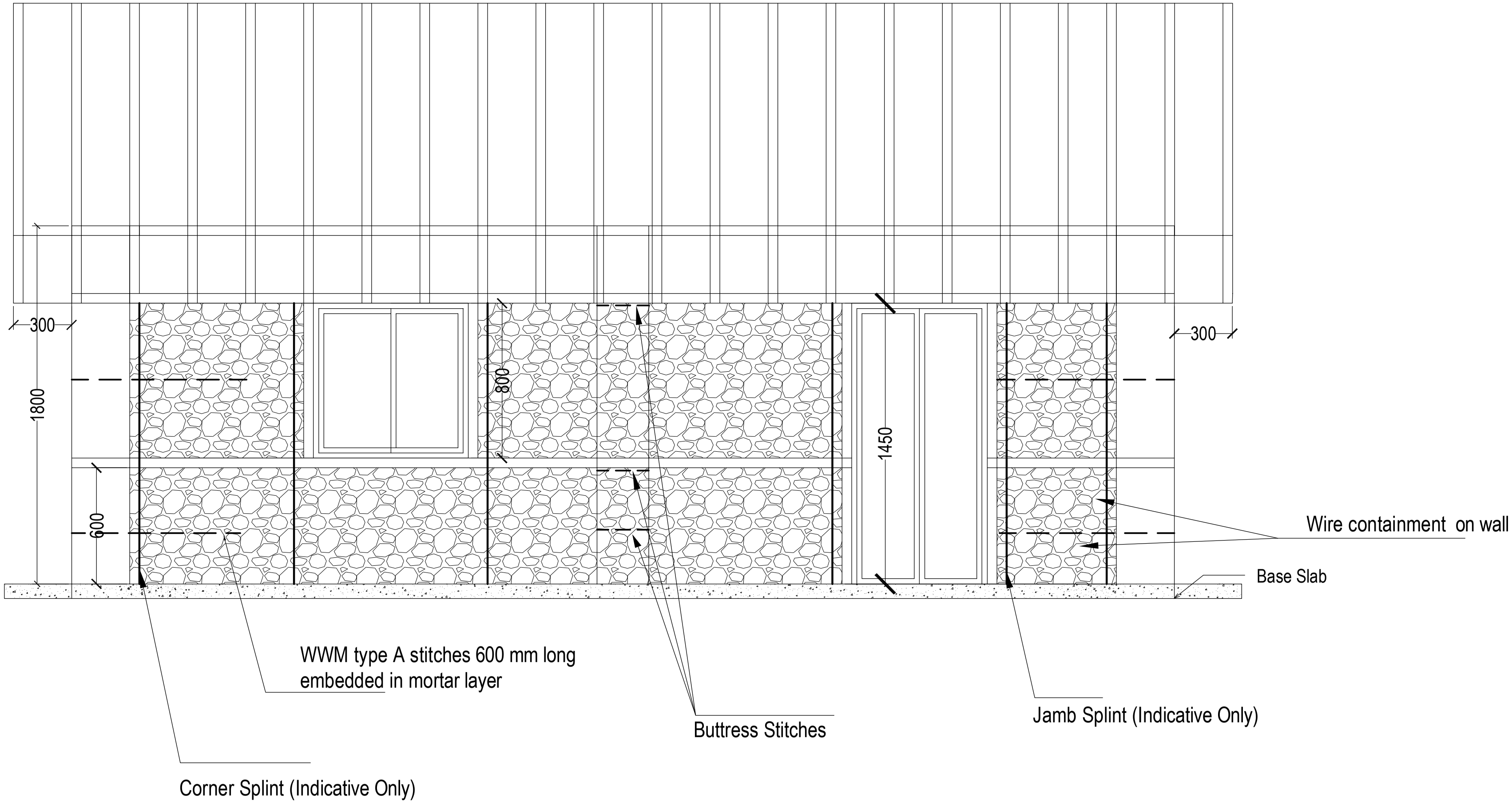
Note: All dimensions are in mm

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (Two Third Scale Drawings) Type# 4	Sill Band Detail Lintel Band Detail Eaves Band Detail	Dr. Qaisar Ali Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: September 2018 Scale: Read As Shown Dwg. No. 08



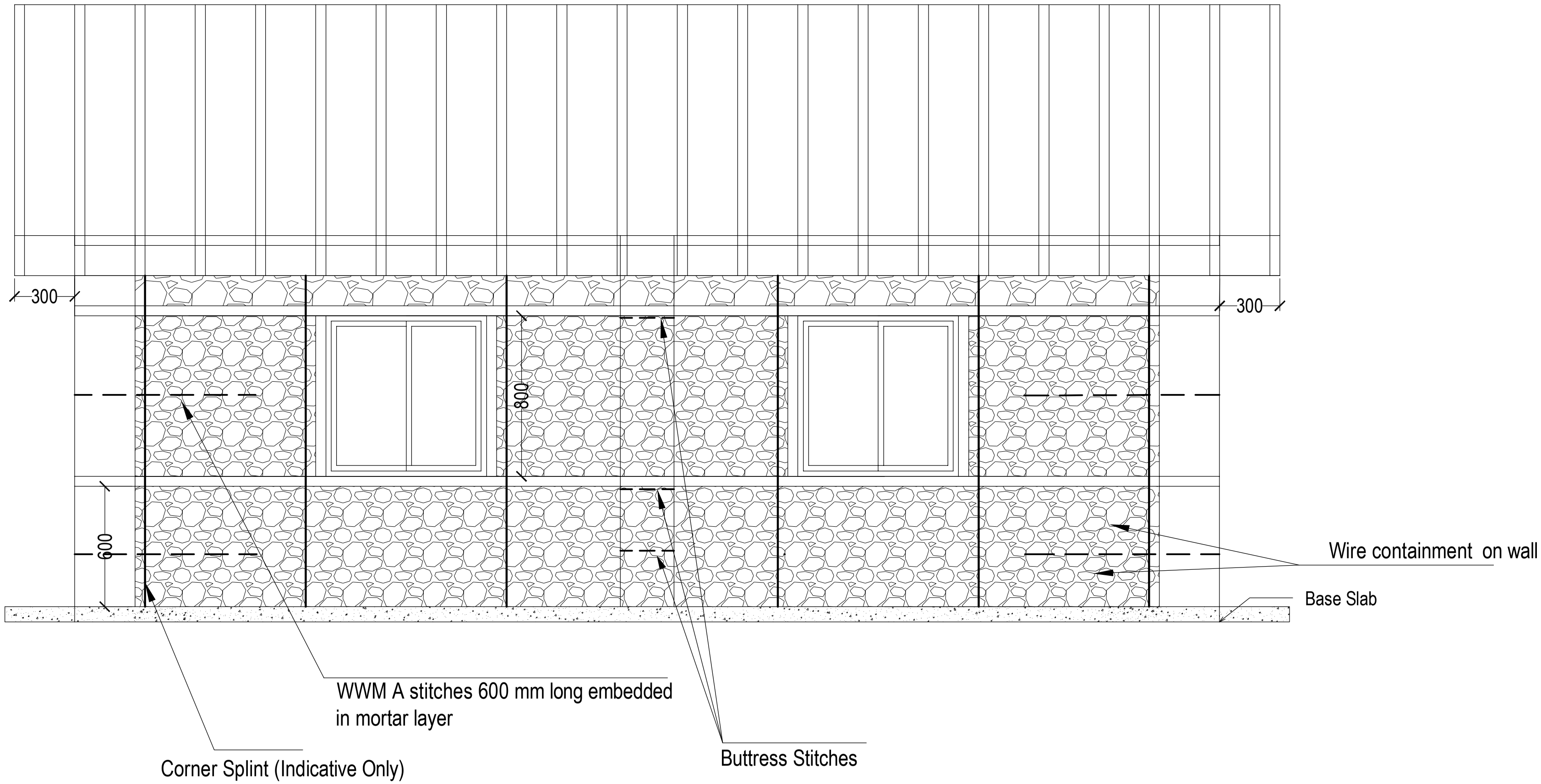
Side Elevation

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (Two Third Scale Drawings) Type# 4	Side Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 09



Front Elevation

Consultant Name: University of Engineering and Technology Peshawar.	Client Name: ADB Asian Development Bank	Design Type: Semidressed Stone Masonry with Timber Bands and wire containment (Two Third Scale Drawings) Type# 4	TITLE Front Elevation	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad; Drafted by: Engr. Attaur Rahman	Date: September 2018; Scale: Read As Shown; Dwg. No. 10



Back Elevation

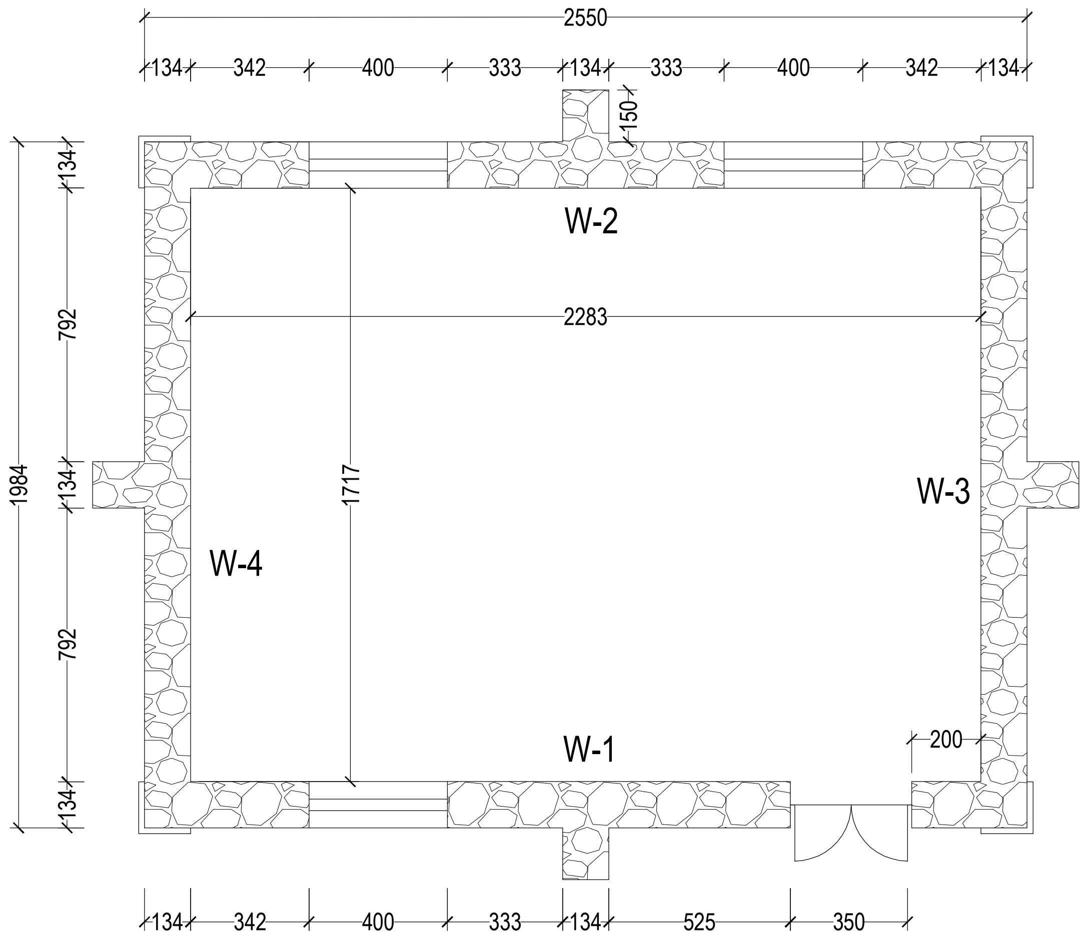
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (Two Third Scale Drawings) Type# 4	Back Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 11

Appendix D1 – School Design Detailed Drawings-1/3rd Scale Model (Type Design 1)

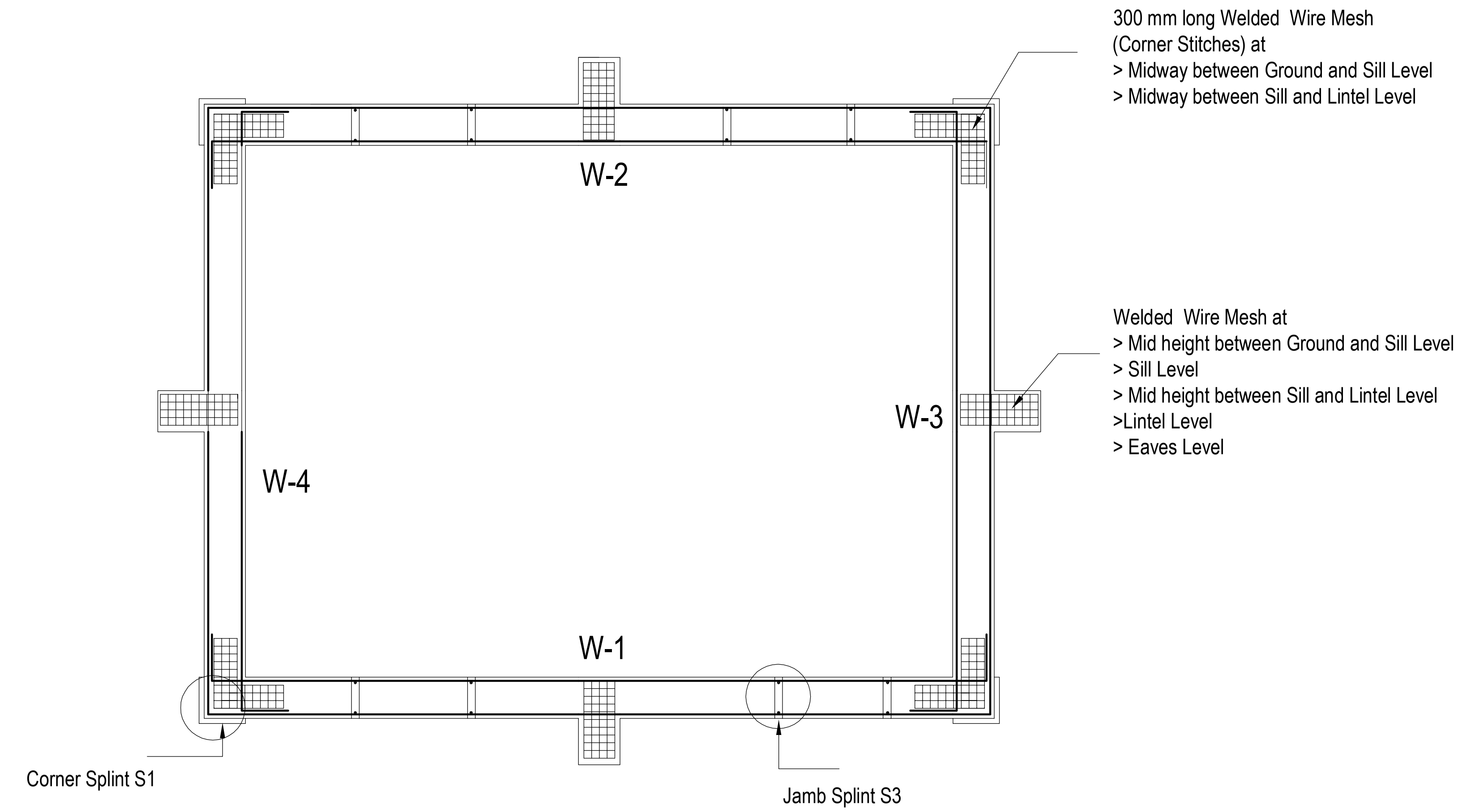
Proposed One Third Drawings of Stone Masonry in Cement Stabilized Mud Mortar and RCC Bands

Type 1

Asian Development Bank



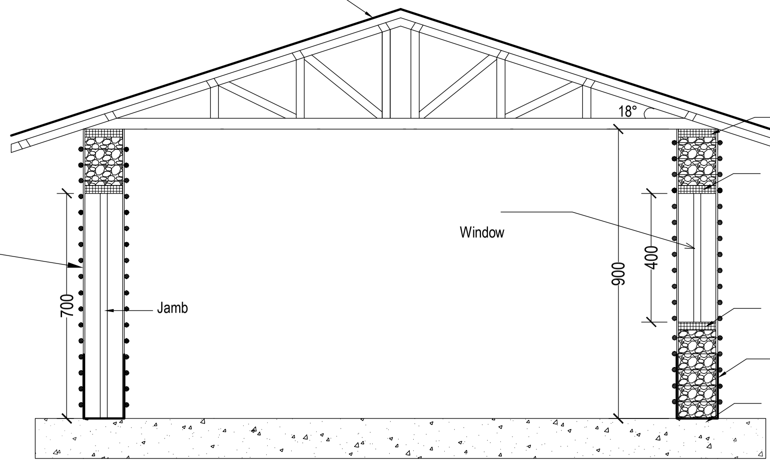
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: November 2017
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type # 1	FLOOR PLAN	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 01



Note: Stirrups not shown for clarity.

Splints and Stitch Details

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type # 1	Stitch Details Corner Splint Jamb Splint	Dr. Qaisar Ali Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: November 2017 Scale: Read As Shown Dwg. No. 02



At Ceiling band, the Vertical Wires of Containment of both the exterior and interior faces passes through the ceiling band at required development length and are intertwined together, (see fig:1).

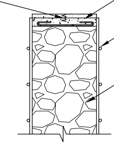
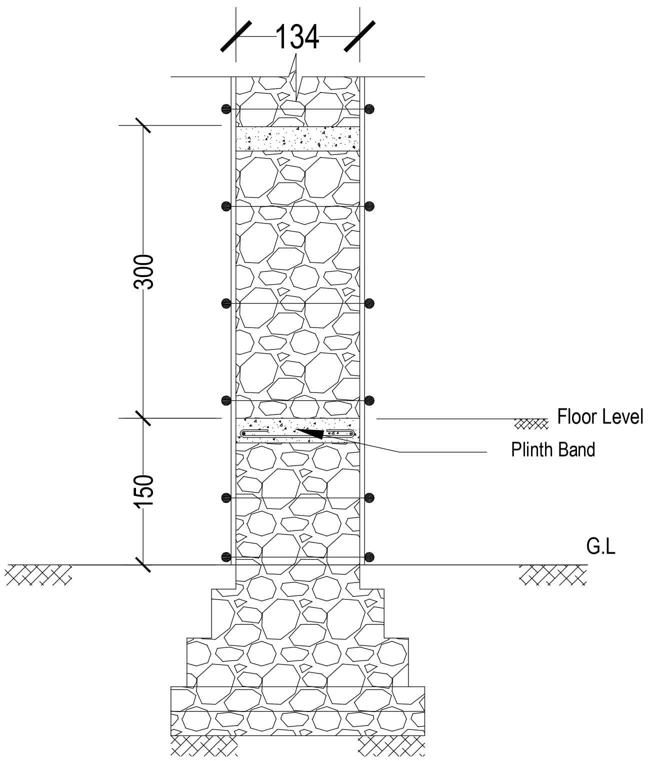


Figure: 01

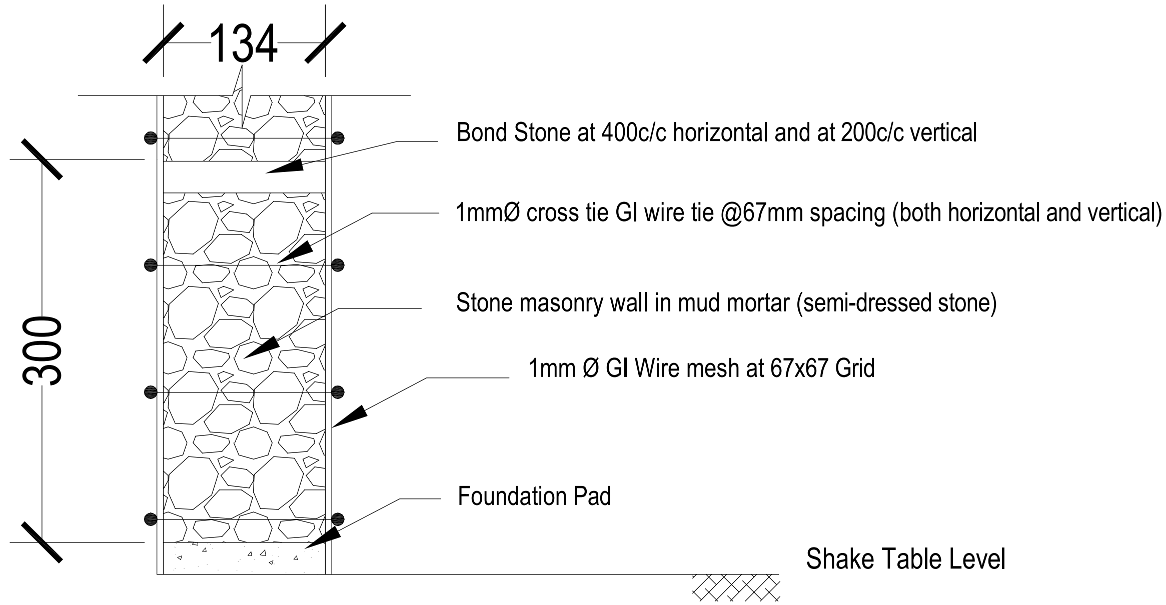
t

Levels	
Ridge Level	+1347 mm
CeilingLevel	+900 mm
Lintel Level	+700 mm
Sill Level	+300 mm
Base Slab Level	+00 mm

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type # 1	Structural Section	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: November 2017 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 03

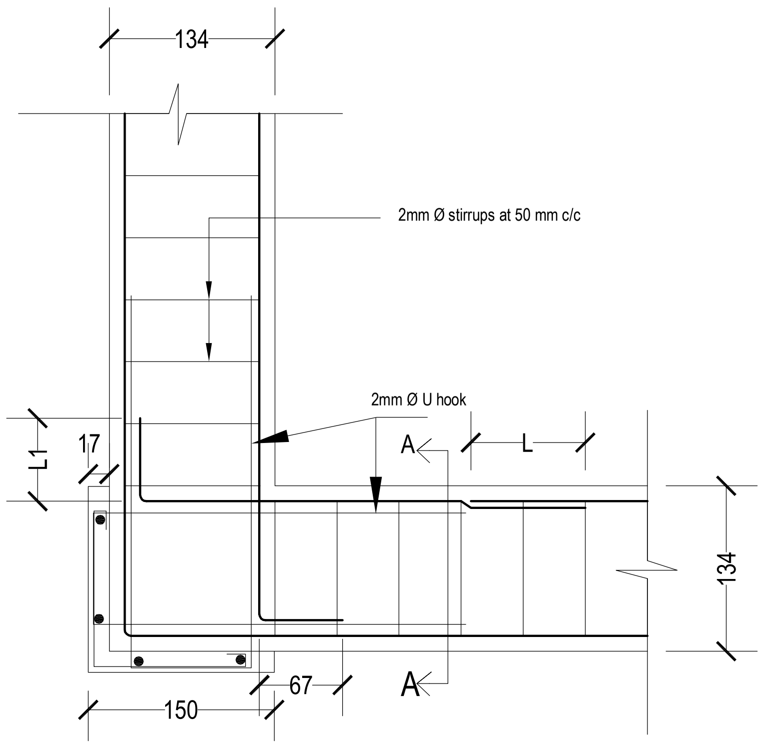


Wall Section
(Field Condition)

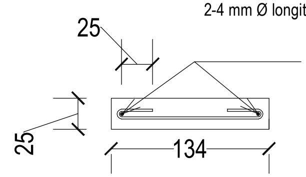


Wall Section
(Test Model in Lab)

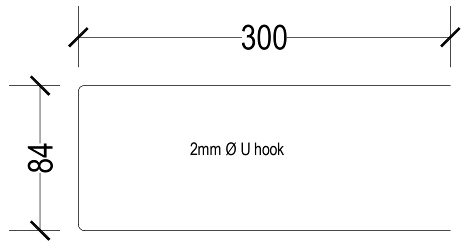
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type # 1	Wall Section	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: November 2017 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 04



Note: The scaling is based on bar diameter rather than x-sectional area.



Section at A-A
Plinth, Sill Band

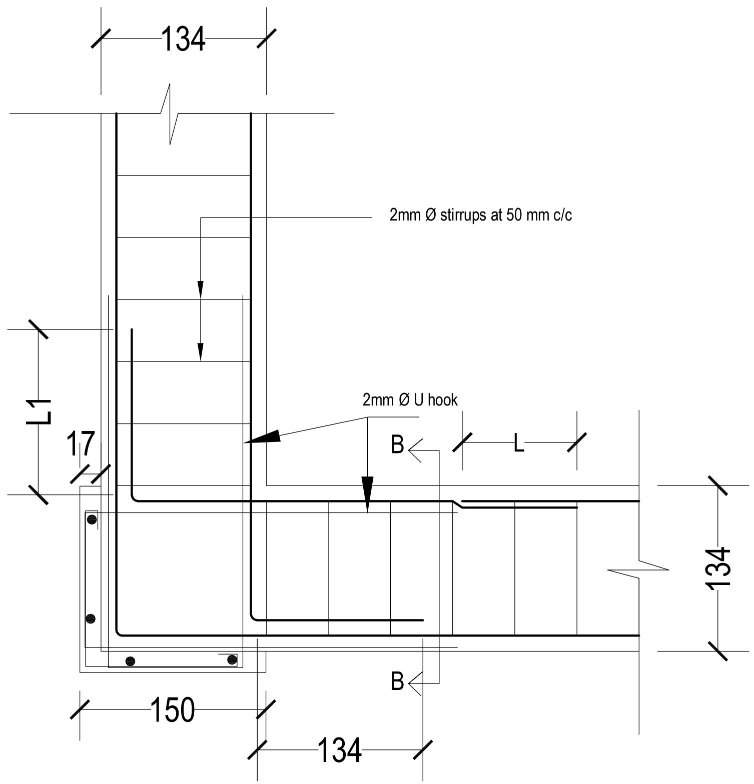


Bar Diameter Ø mm	Lap Length, L mm	Hook Length, L1 mm
4	220	108
6	300	188

Note: Containment wires not shown for clarity.

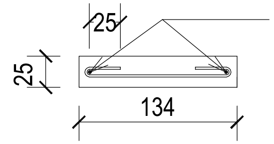
Corner Junction Plinth, Sill Band

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: November 2017
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type # 1	Corner Junction at Plinth, Sill Band	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 05

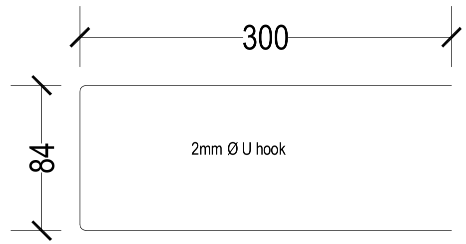


Note: The scaling is based on bar diameter rather than x-sectional area.

2-6 mm Ø longitudinal rebar with 2mmØ stirrups @50mm c/c



Section at B-B Lintel Band

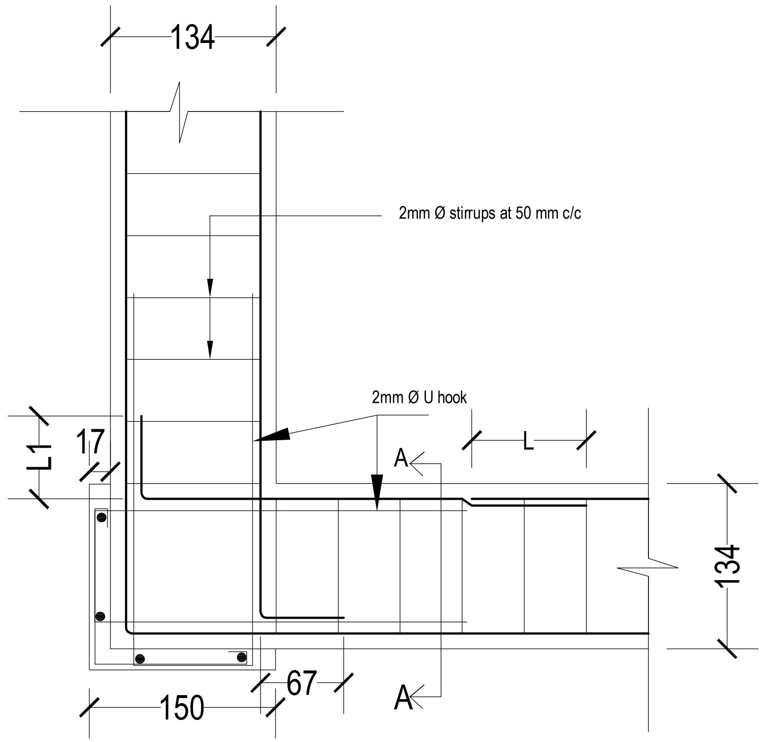


Bar Diameter Ø mm	Lap Length, L mm	Hook Length, L1 mm
4	220	108
6	300	188

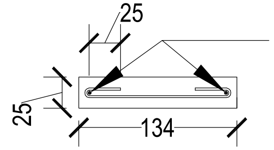
Note: Containment wires not shown for clarity.

Corner Junction Lintel Band

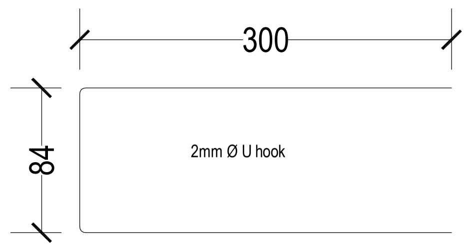
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	ADB Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type # 1	Corner Junction at Lintel Band	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: November 2017 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 06



Note: The scaling is based on bar diameter rather than x-sectional area.



Section at A-A
Eaves Band

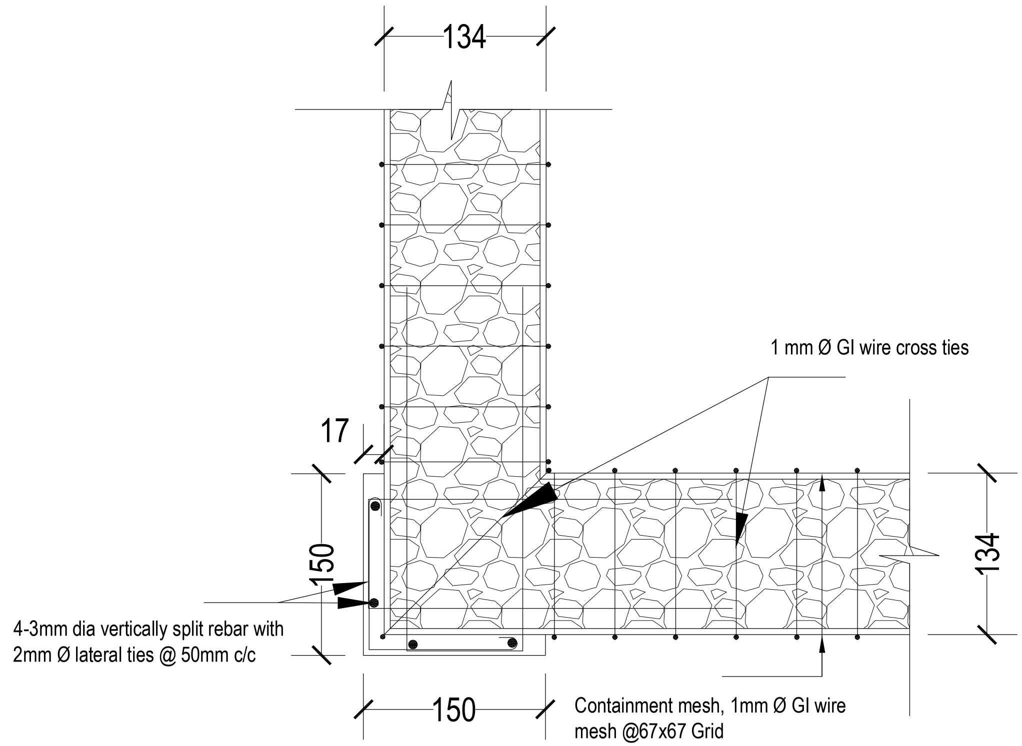


Bar Diameter Ø mm	Lap Length, L mm	Hook Length, L1 mm
4	220	108
6	300	188

Note: Containment wires not shown for clarity.

Corner Junction Eaves Band

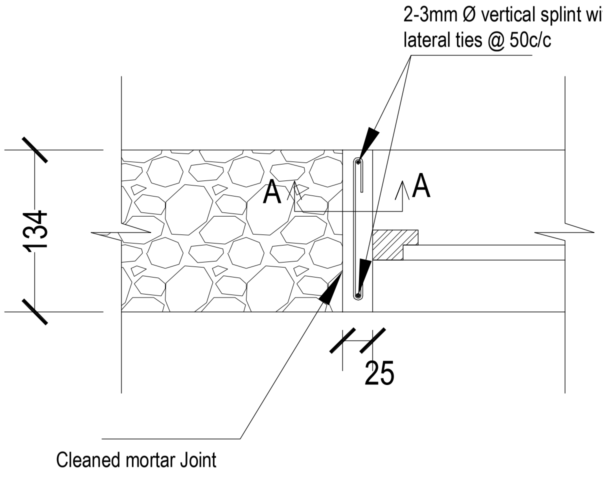
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type # 1	Corner Junction at Eaves Band	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: November 2017
					Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 07

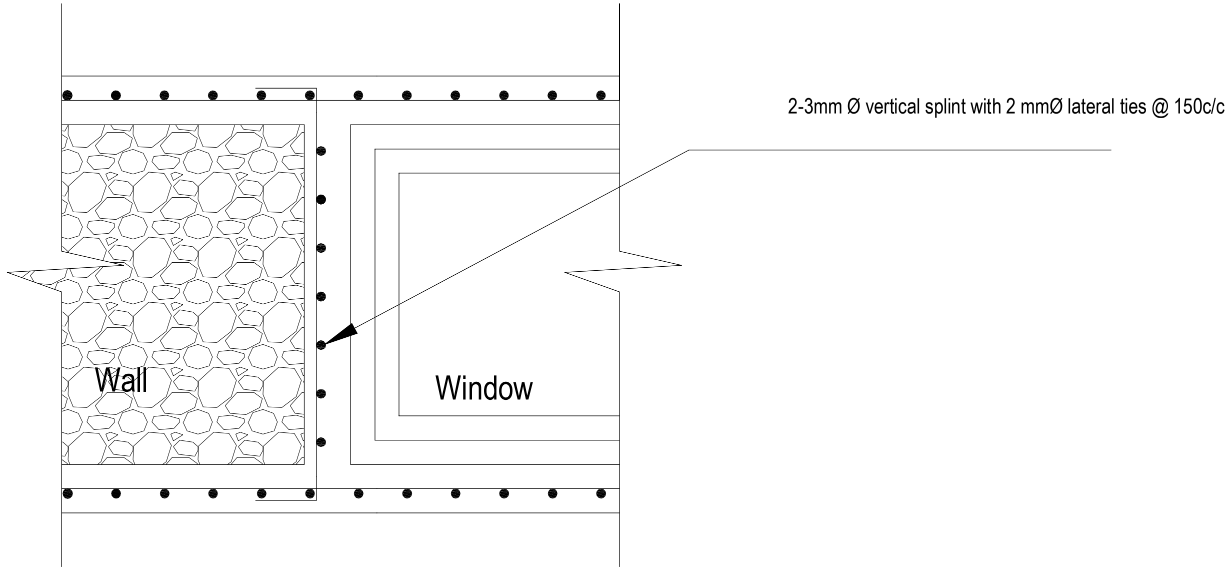


Corner Splint S1

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type # 1	Corner Splint S1	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: November 2017 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 08

Note: The scaling is based on bar diameter rather than x-sectional area.

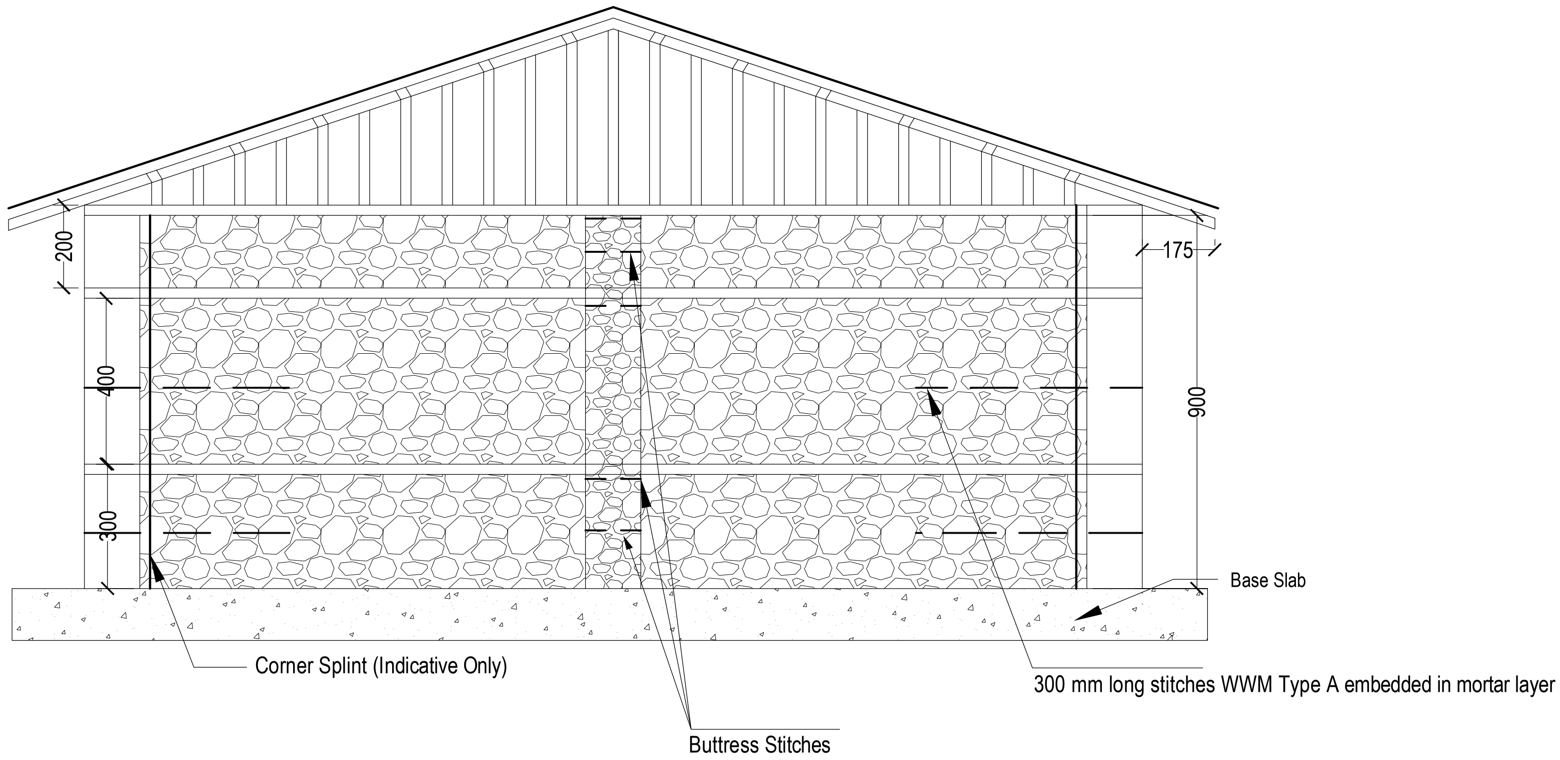




Section at A-A

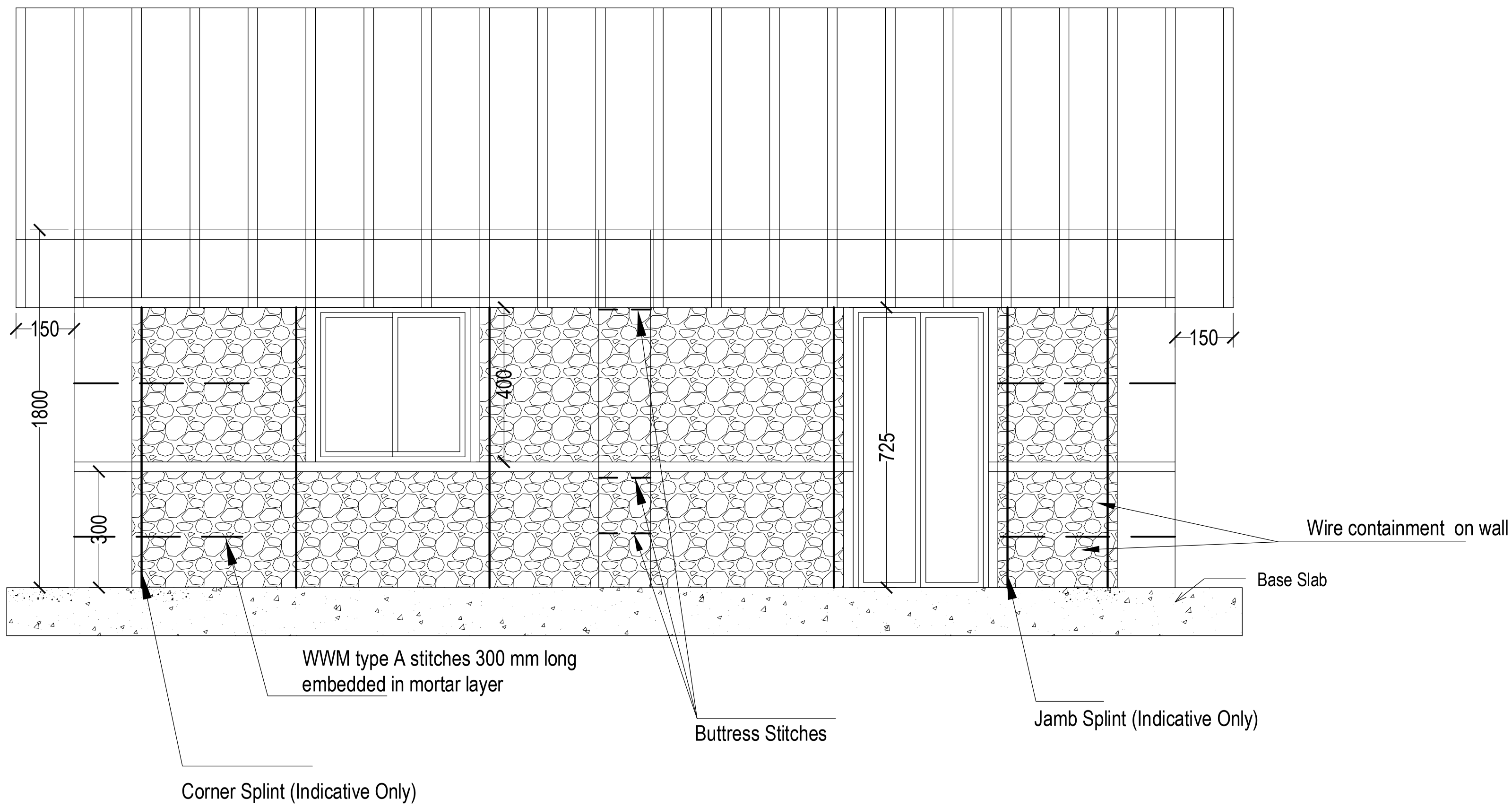
Jamb Splint S3

Consultant Name: University of Engineering and Technology Peshawar.	Client Name: Asian Development Bank	Design Type: Stone Masonry in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type # 1	TITLE Jamb Splint S3	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad	Date: November 2017
				Drafted by: Engr. Attaur Rahman	Scale: Read As Shown
					Dwg. No. 09



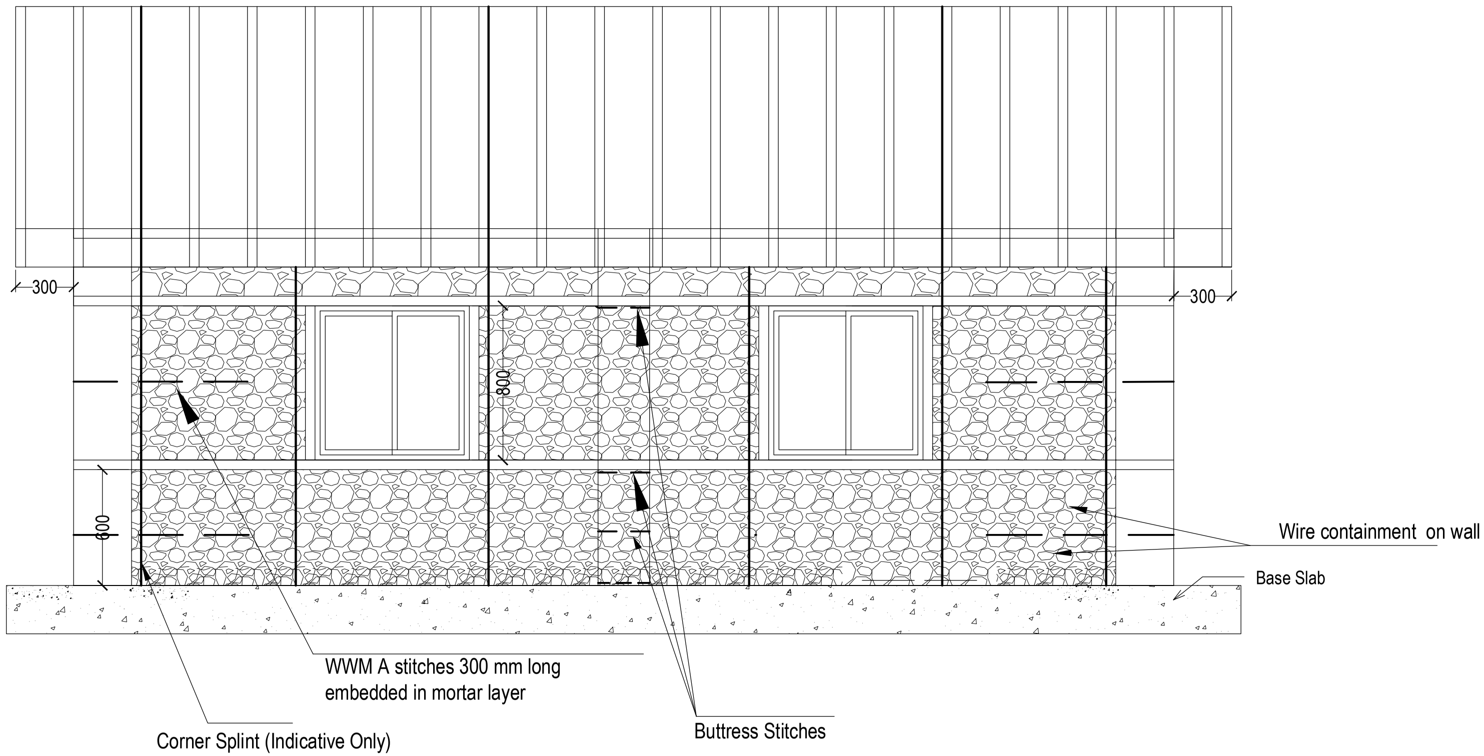
Side Elevation

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: November 2017
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type # 1	Side Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 10



Front Elevation

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type # 1	Front Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: November 2017 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 11



Back Elevation

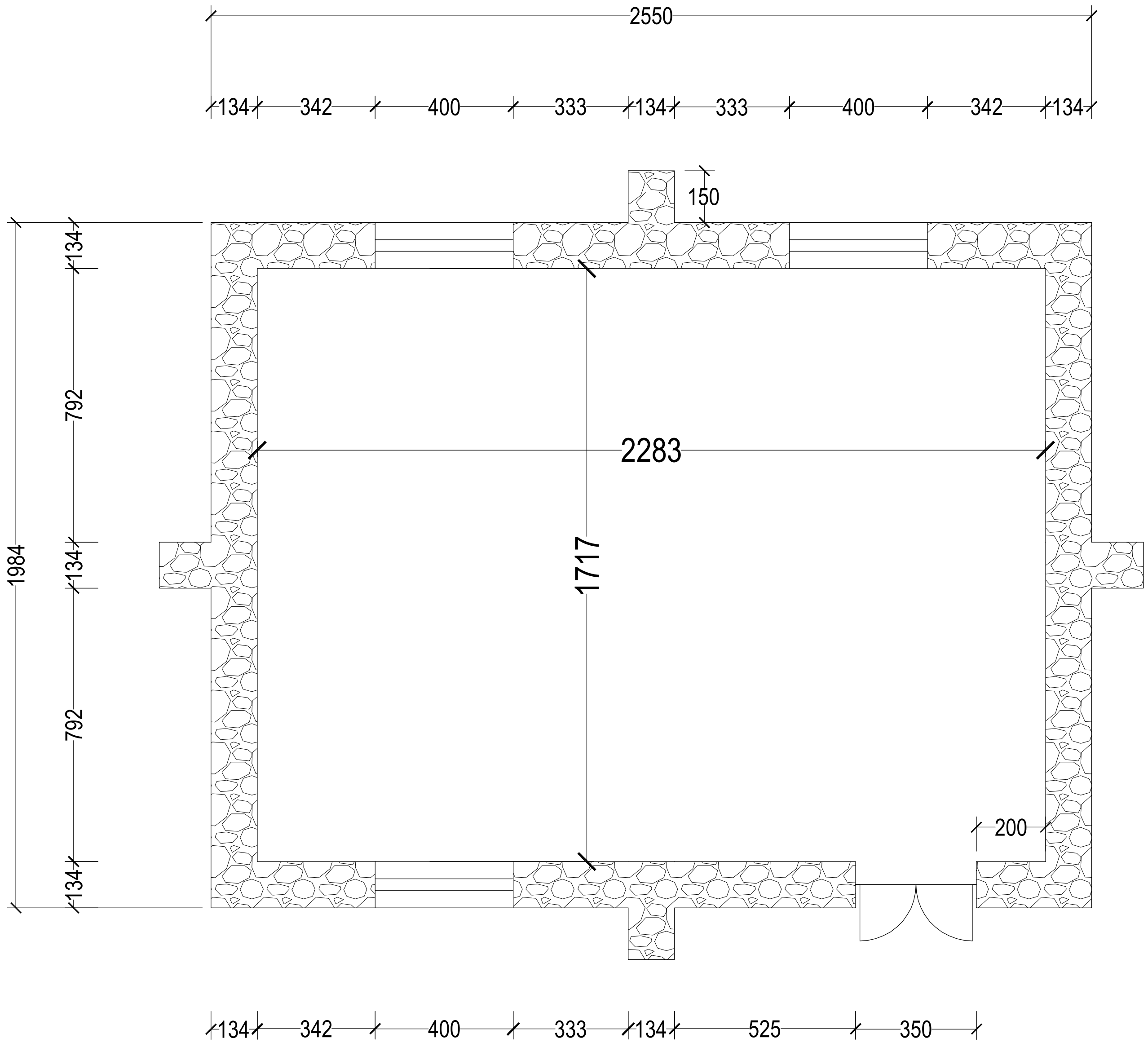
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Stone Masonry in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type # 1	Back Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: November 2017
					Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 12

Appendix D2 – School Design Detailed Drawings-1/3rd Scale Model (Type Design 2)

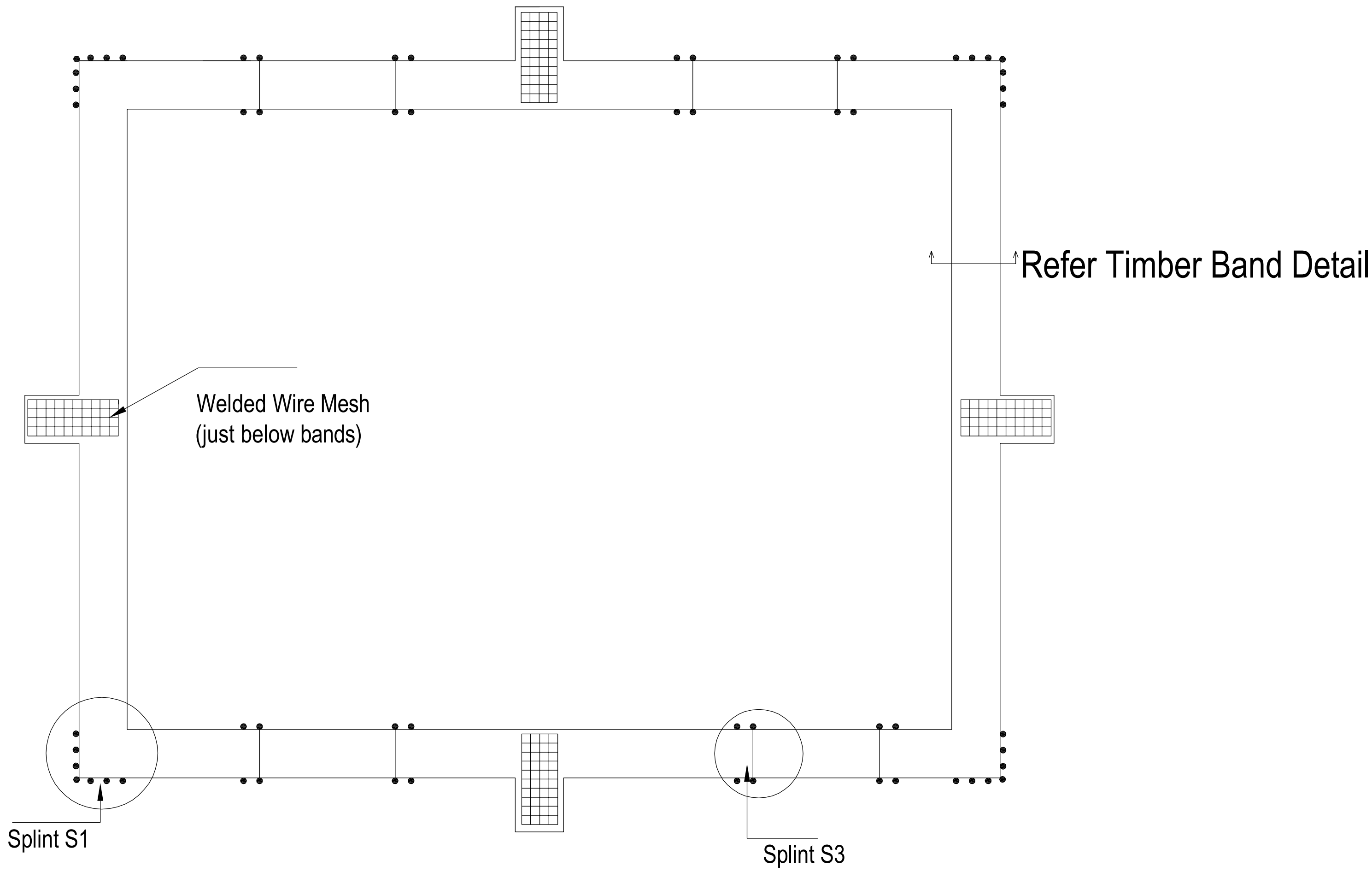
Proposed One-Third Scale Drawings of Semi-dressed Stone Masonry with Gabian mesh/Geogrid bands and Wire Containment

Type 2

Asian Development Bank



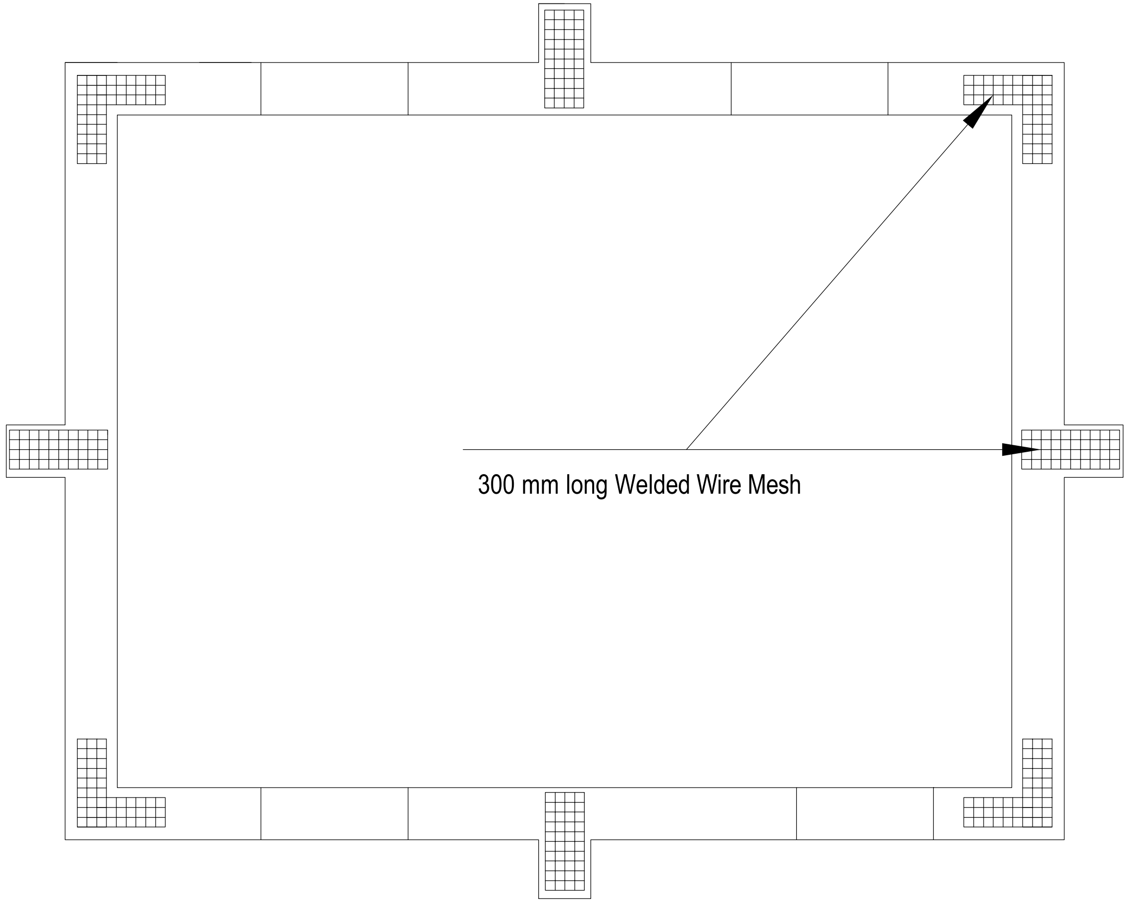
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (One Third Scale Drawings) Type# 2	FLOOR PLAN	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 01



- Containment wires not shown for clarity.
- Plinth band not provided.
- Wires shown for splints are representative only.

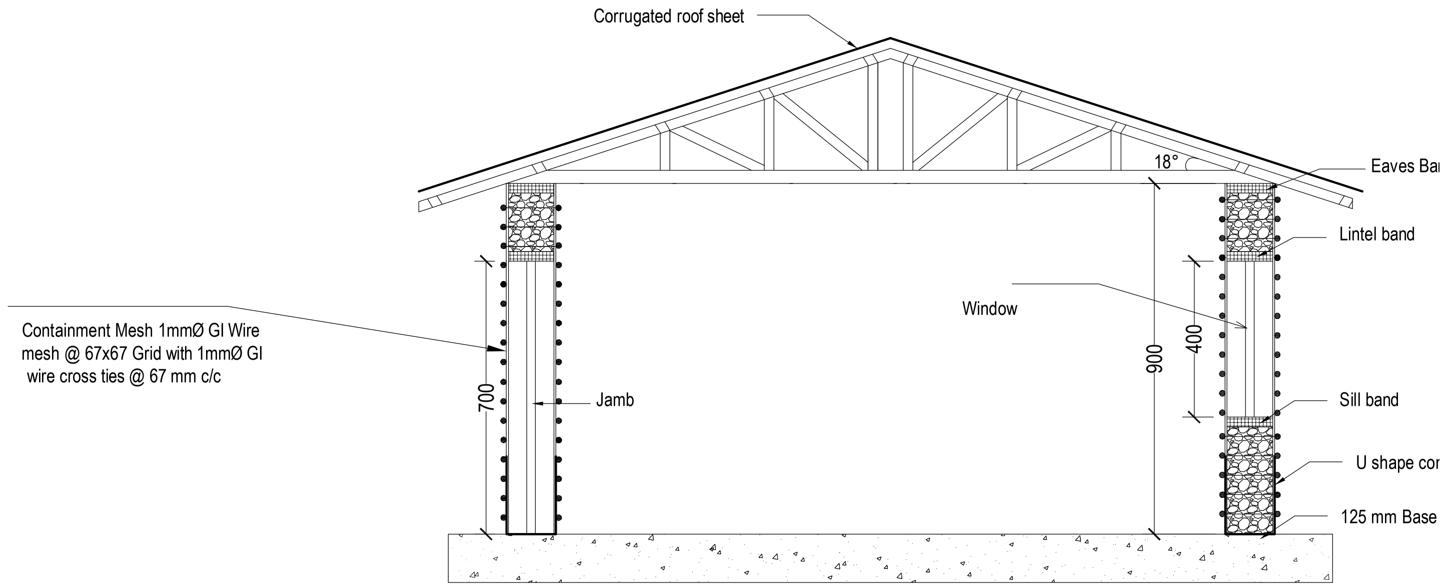
- Provide Buttress Stitches at
  > Plinth, Sill, Lintel and Eaves Level.
  > Between Plinth and Sill.
  > Between Lintel and Eaves Level.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (One Third Scale Drawings) Type# 2	Band, Vertical Wires at Wall-Junctions, Jambs and Butresses Stitches	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 02



- Welded Wire Mesh (WWM) placed midway between
    1. DPC and Sill Level, and
    2. Sill and Lintel Level.
- WWM embedded in mortar layer.
- Splints S1 and S3 not shown for clarity.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	ADB Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (One Third Scale Drawings) Type# 2	Stitch Detail	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 03

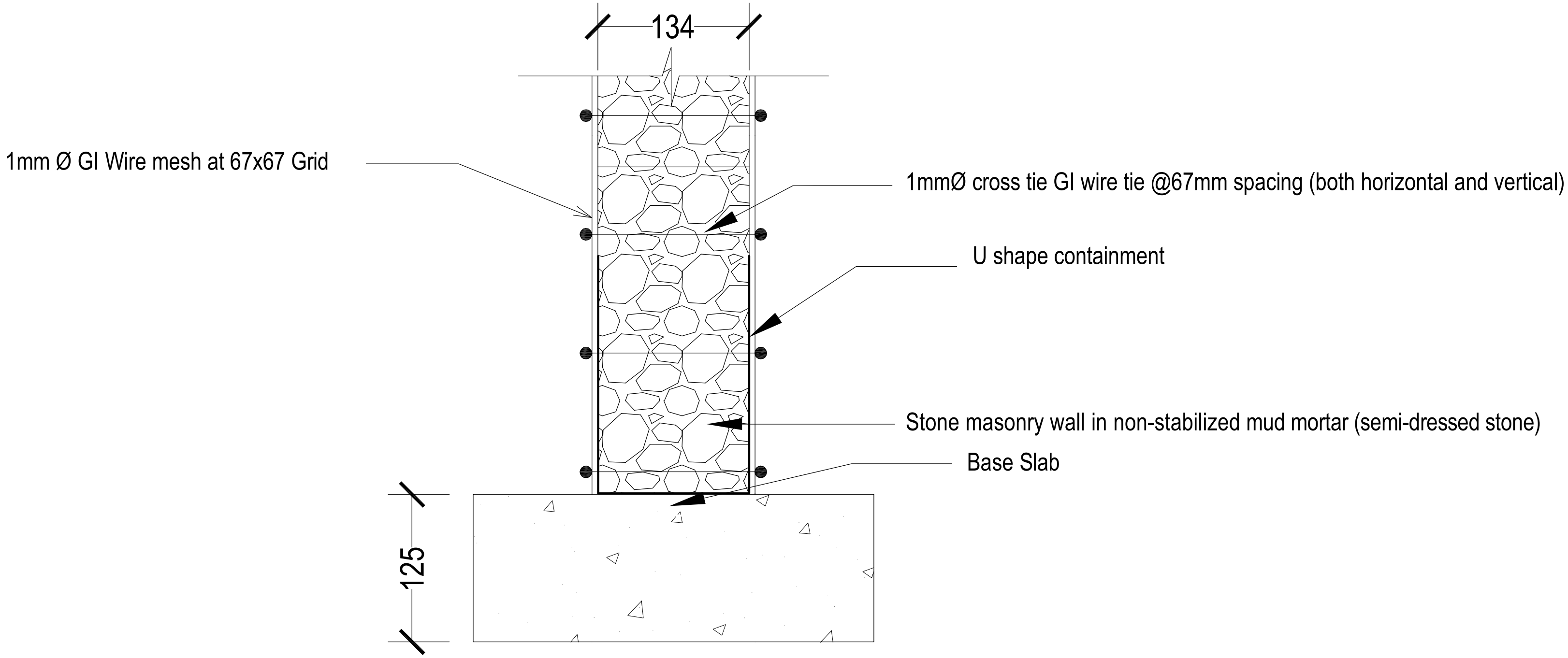


Note:

1. At eaves band, the vertical wires from both the interior and exterior faces connects at top of the eaves band and hence intertwined.
2. Containment Wires in the shape of U is placed below the first course and then it is intertwined with the vertical containment. U shape is shown as bold lines in the drawing.

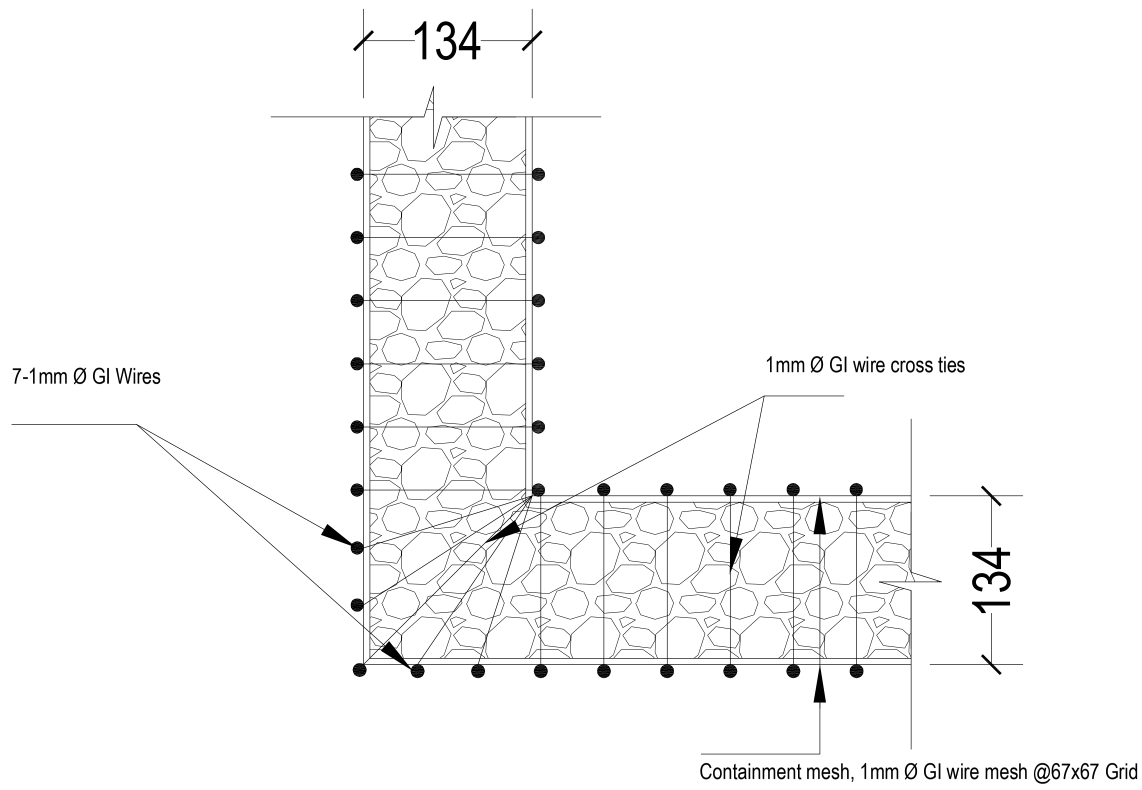
Levels	
Ridge Level	+1347 mm
CeilingLevel	+900 mm
Lintel Level	+700 mm
Sill Level	+300 mm
Base Slab Level	+00 mm

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (One Third Scale Drawings) Type# 2	Structural Section	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 04



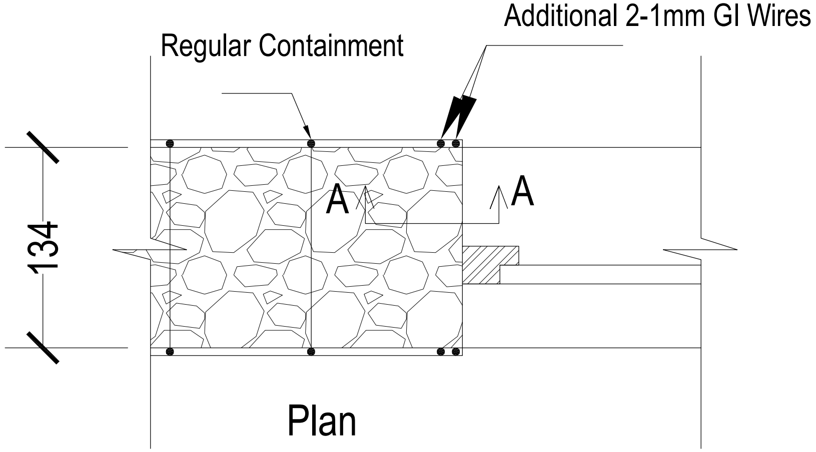
Wall Section

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (One Third Scale Drawings) Type# 2	Wall Section Detail	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 05

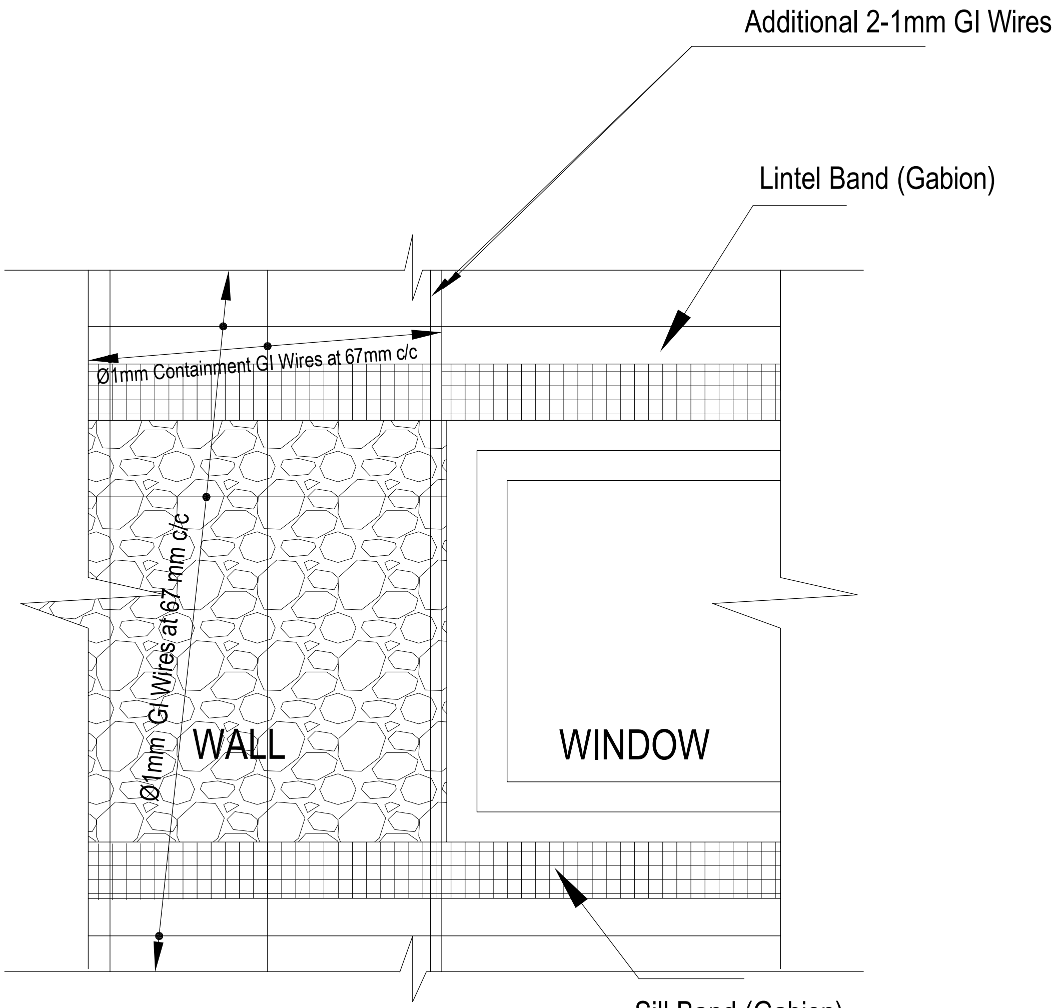


Corner Splint S1

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (One Third Scale Drawings) Type# 2	Corner Splint S1 Detail	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 06



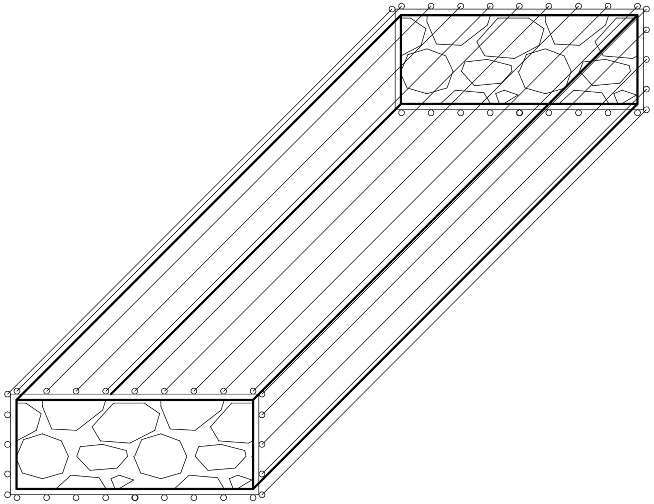
Plan



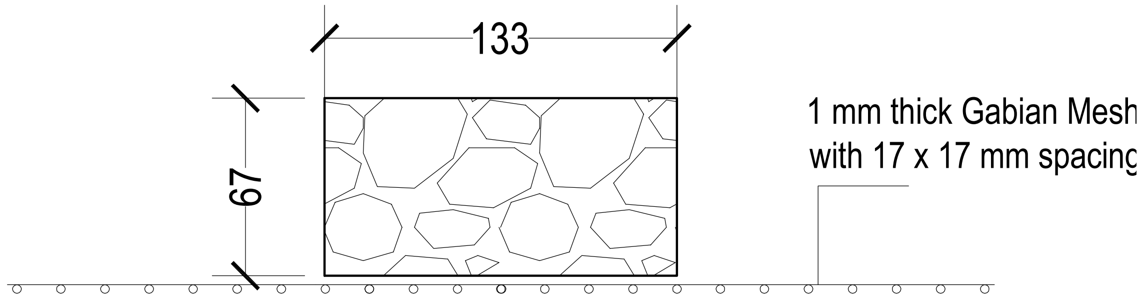
Section at A-A

Jamb Splint S3

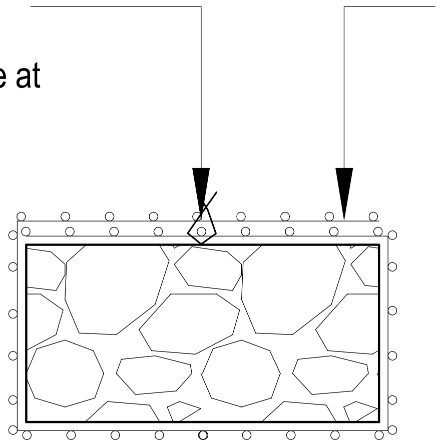
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (One Third Scale Drawings) Type# 2	Jamb Splint S3 Detail	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 07



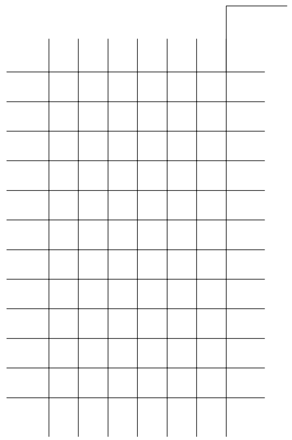
3D view of Gabian Band (Cross wires are not shown for clarity at mid sections)



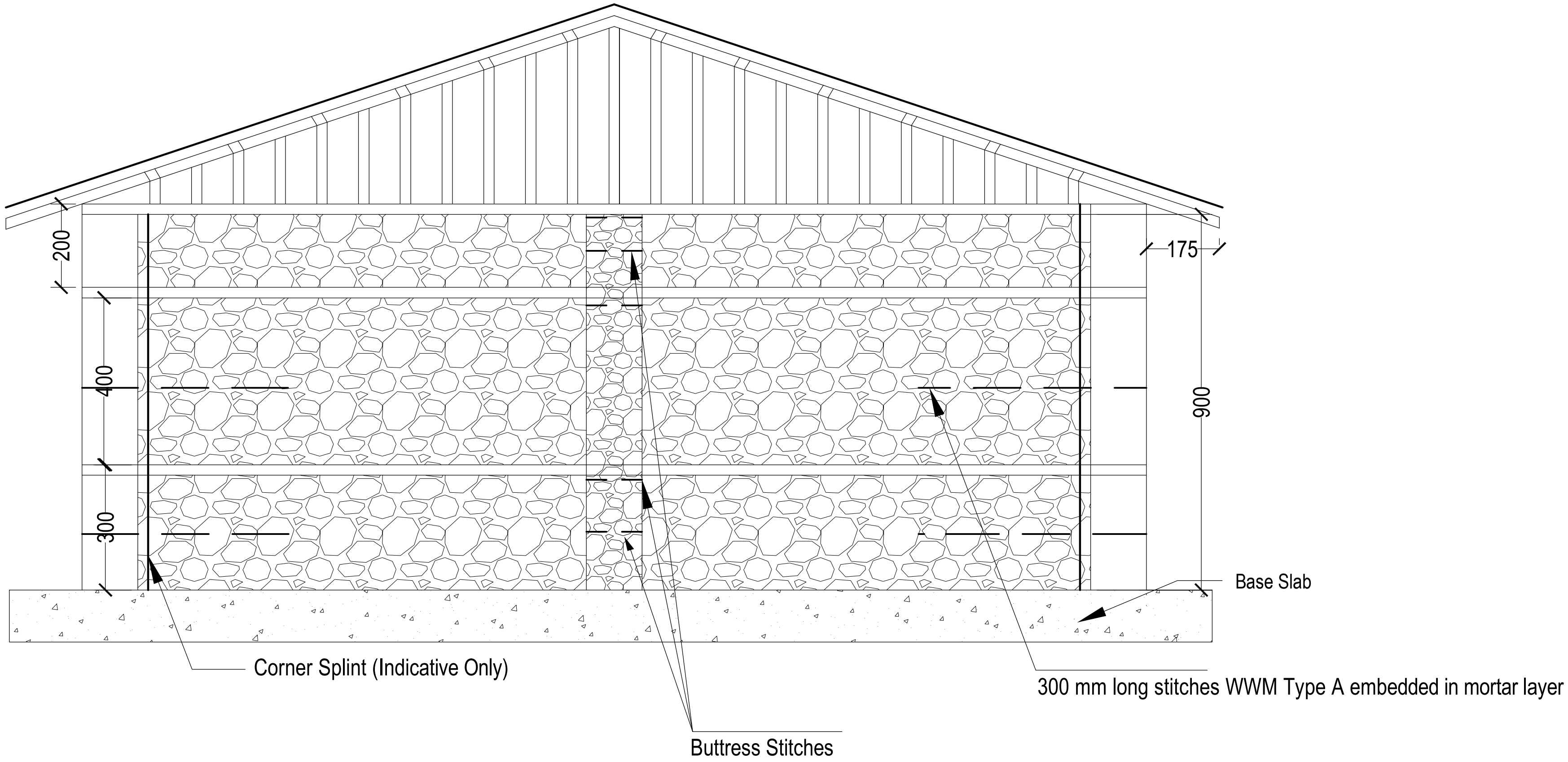
X-Section of Wall with Unwraped Gabian Mesh



X-Section of Wall with wraped Gabian Mesh

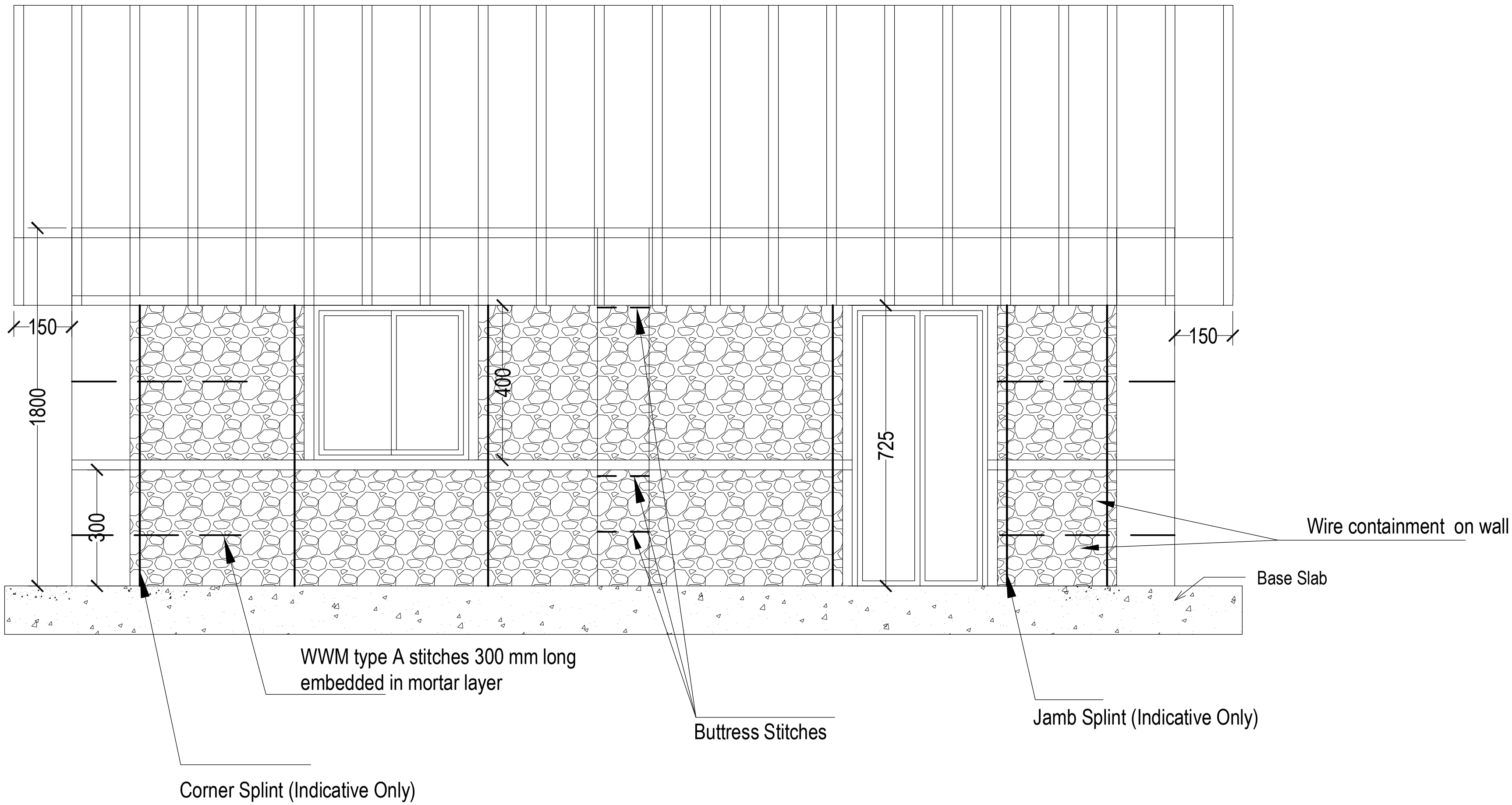


Consultant Name: University of Engineering and Technology Peshawar.	Client Name: ADB Asian Development Bank	Design Type: Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (One Third Scale Drawings) Type# 2	TITLE Lintel Band Detail Sill Band Detail Eaves Band Detail	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: September 2018 Scale: Read As Shown Dwg. No. 08



Side Elevation

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (One Third Scale Drawings) Type# 2	Side Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 09



Front Elevation

Consultant Name: University of Engineering and Technology Peshawar.	Client Name: Asian Development Bank	Design Type: Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (One Third Scale Drawings) Type# 2	TITLE: Front Elevation	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad	Date: September 2018
				Drafted by: Engr. Attaur Rahman	Scale: Read As Shown
					Dwg. No. 10

Back Elevation

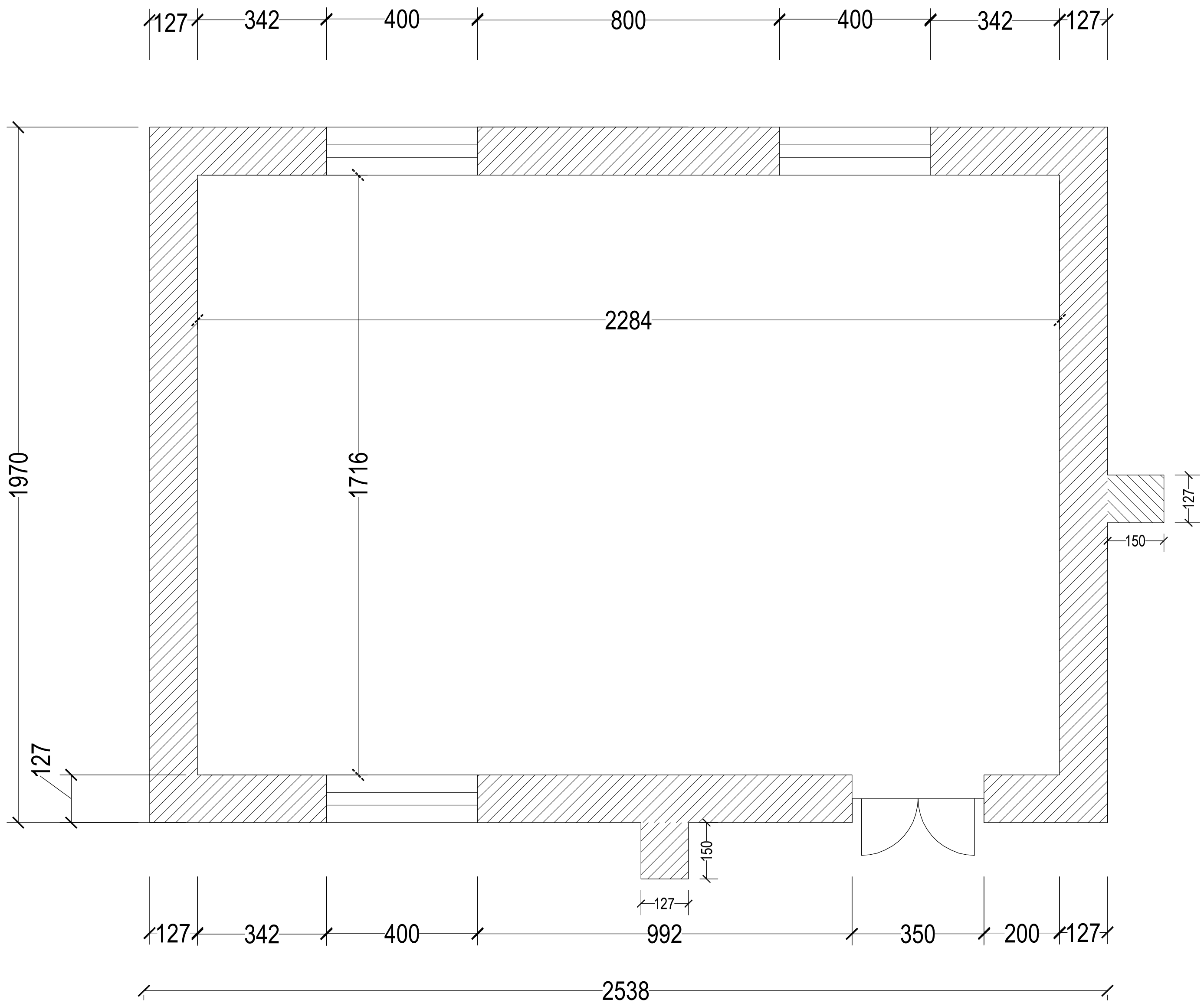
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabion mesh/Geogrid Bands and wire containment (One Third Scale Drawings) Type# 2	Back Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 11

Appendix D3 – School Design Detailed Drawings-1/3rd Scale Model (Type Design 3)

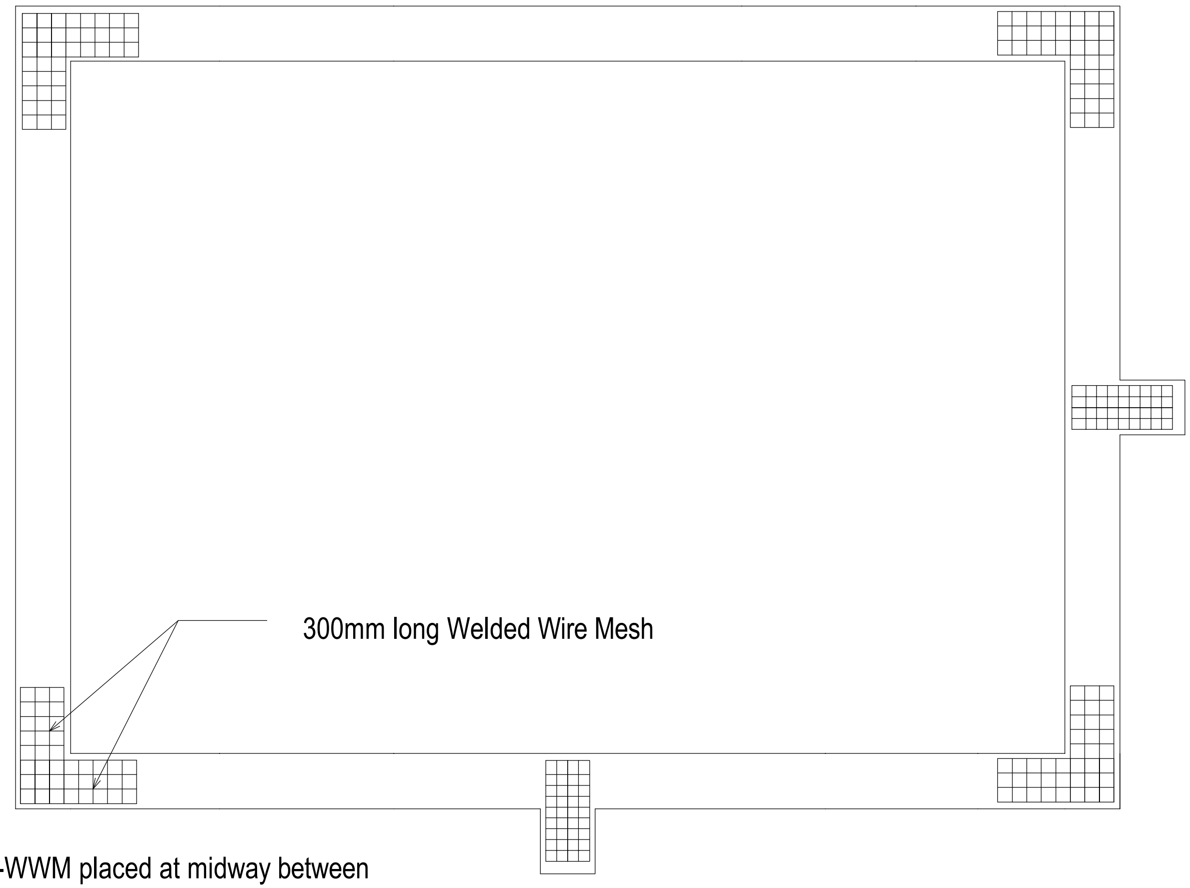
Proposed One Third Drawings of Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands

Type 3

Asian Development Bank

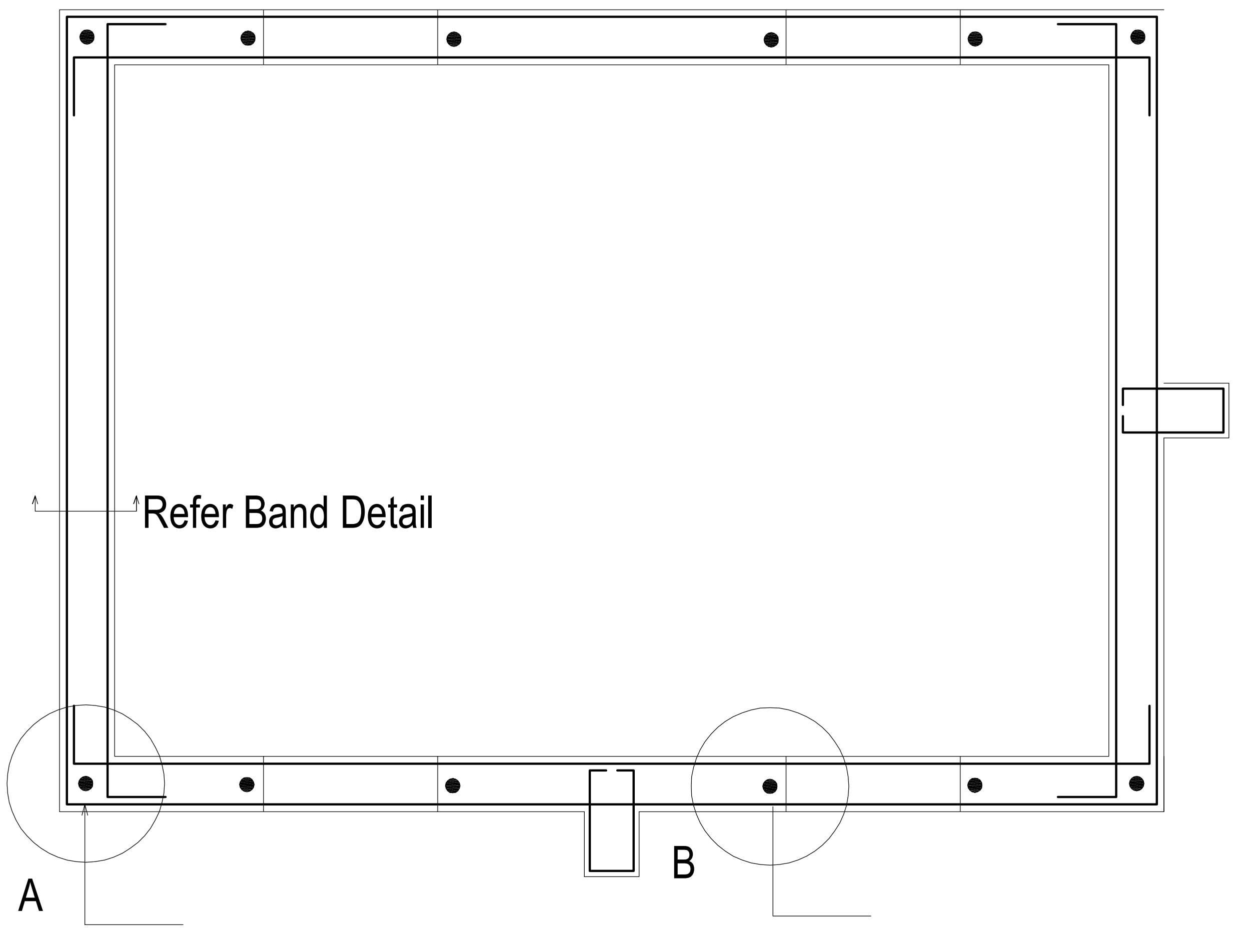


Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type# 3	FLOOR PLAN	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 01



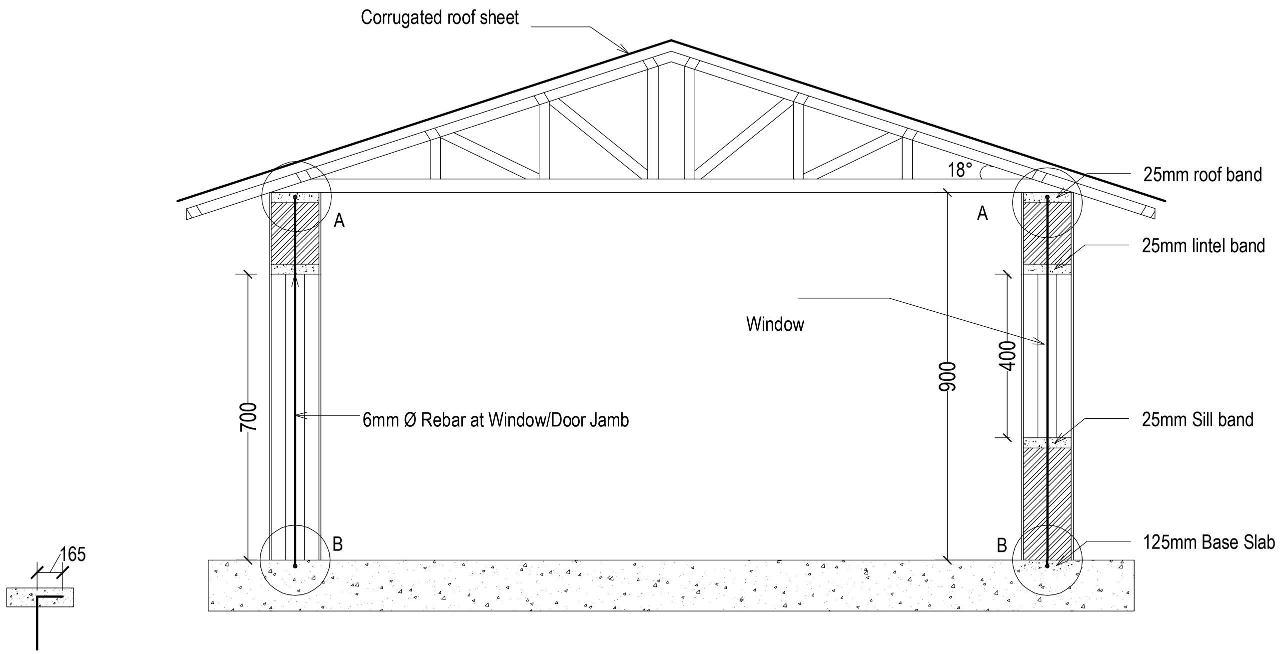
-WWM placed at midway between
> DPC and Sill Level
> Sill and Lintel Level
-WWM embedded in mortar layer

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type# 3	Stitch Details	Dr. Qaisar Ali, Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 02



Stirrups not shown for Clarity

Consultant Name: University of Engineering and Technology Peshawar.	Client Name: Asian Development Bank	Design Type: Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type# 3	TITLE Jamb Plan at Plinth, Sill, Lintel and Eaves Level	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad	Date: September 2018
					Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 03

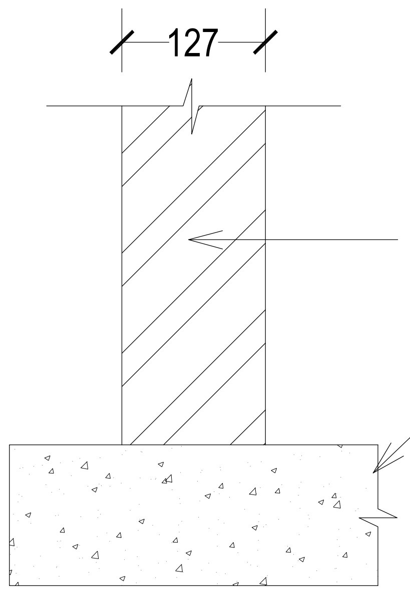


'A'
Connection of Jamb rebar with Ceiling Band

'B'
Jamb rebars were connected to the base slab using epoxy.

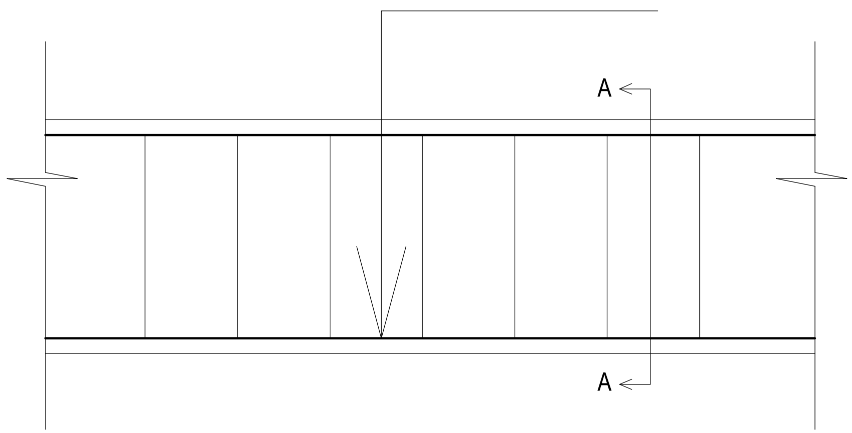
Levels	
Ridge Level	+1297 mm
Floor Level	+900 mm
Lintel Level	+700 mm
Sill Level	+300 mm
Plinth Level	+00 mm

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	ADB Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type# 3	Structural Section	Dr. Qaisar Ali, Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 04

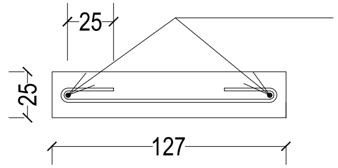


Wall Section

Consultant Name: University of Engineering and Technology Peshawar.	Client Name: Asian Development Bank	Design Type: Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type# 3	TITLE Wall Section	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad	Date: September 2018
					Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 05



Typical Band Plan

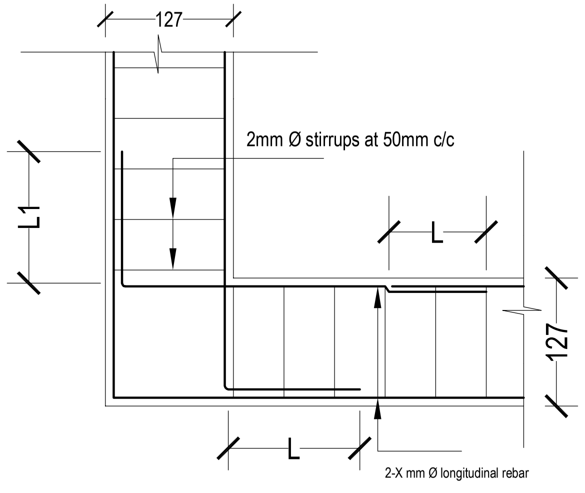


Section at A-A
Band Detail

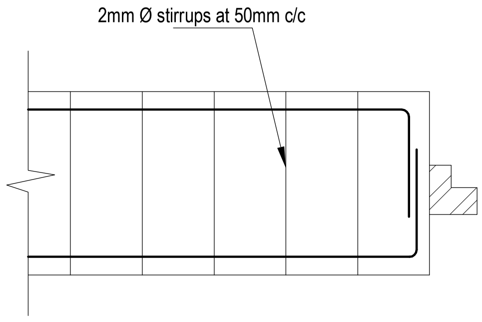
Note: The scaling is based on bar diameter rather than area.

Rebar Size in Bands	
Band Level	Rebar Diameter (X)
Plinth Level	3.5 mm
Sill Band	3.5 mm
Lintel Band	4 mm
Eaves	4 mm

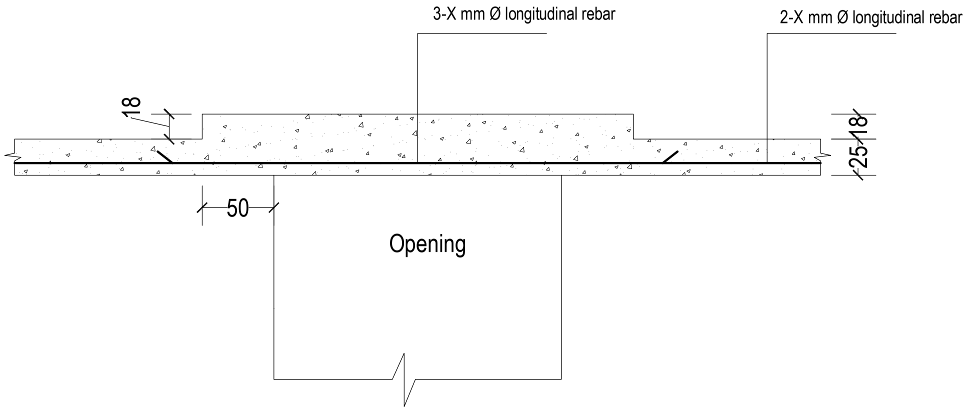
Consultant Name: University of Engineering and Technology Peshawar.	Client Name: ADB Asian Development Bank	Design Type: Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type# 3	TITLE Typical Band Plan	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: September 2018 Scale: Read As Shown Dwg. No. 06



Band Detail at corner junction



Sill Level Band at Door



Lintel Band above Openings

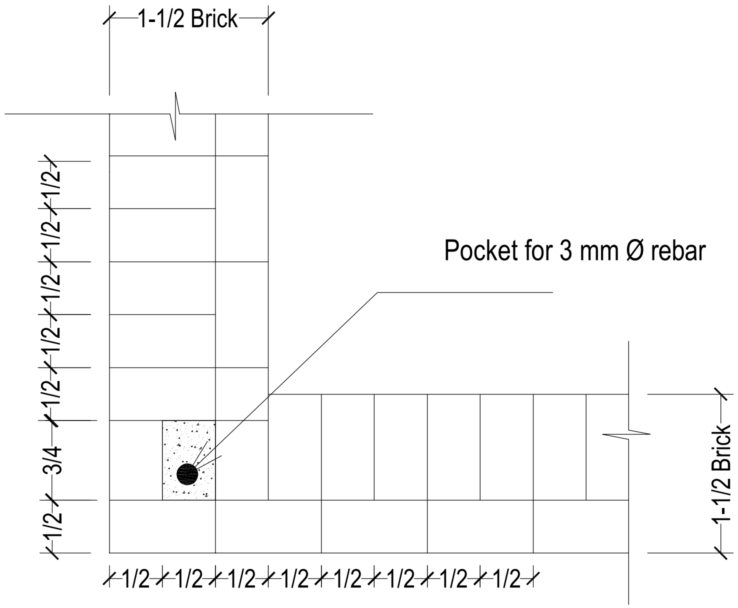
Rebar Diameter	Lap Length, L	Hook Length, L1
3.5 mm	220mm	75 mm
4 mm	300mm	115 mm

Rebar Size in Bands

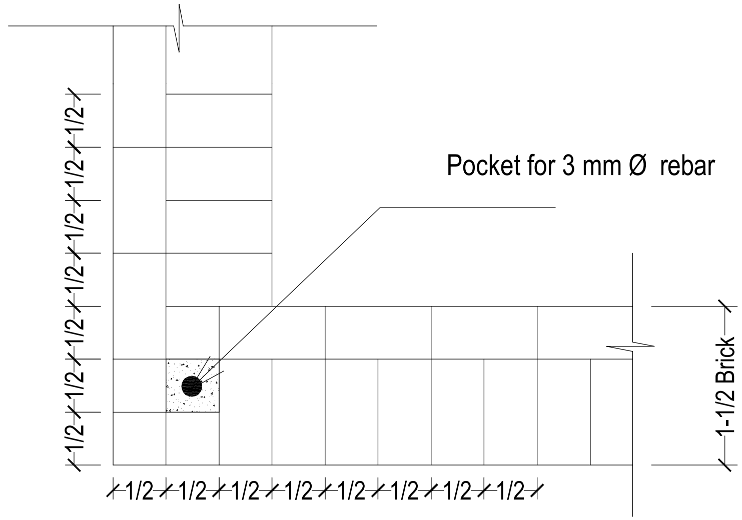
Band Level	Rebar Diameter (X)
Plinth Level	3.5 mm
Sill Band	3.5 mm
Lintel Band	4 mm
Eaves	4 mm

Note: The scaling is based on bar diameter rather than area.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type# 3	Typical Band Detail at Corner Lintel Band Detail above Openings	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 07

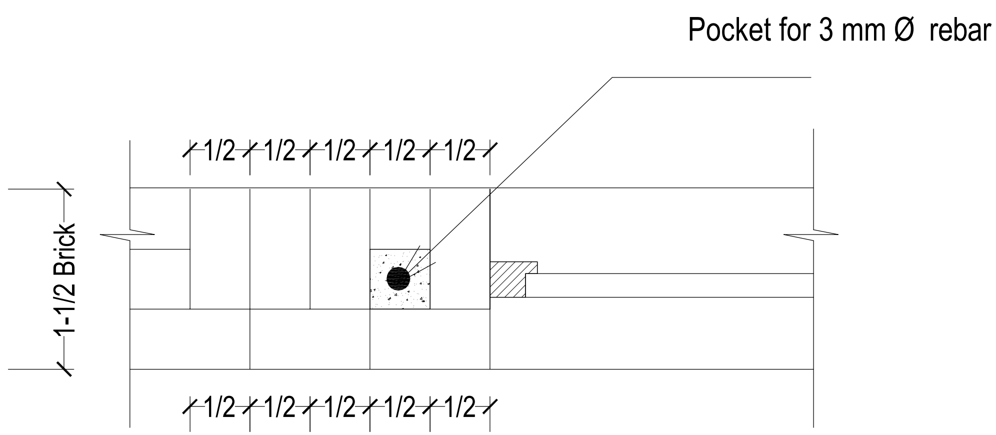


First Layer course
(Corner Junction)

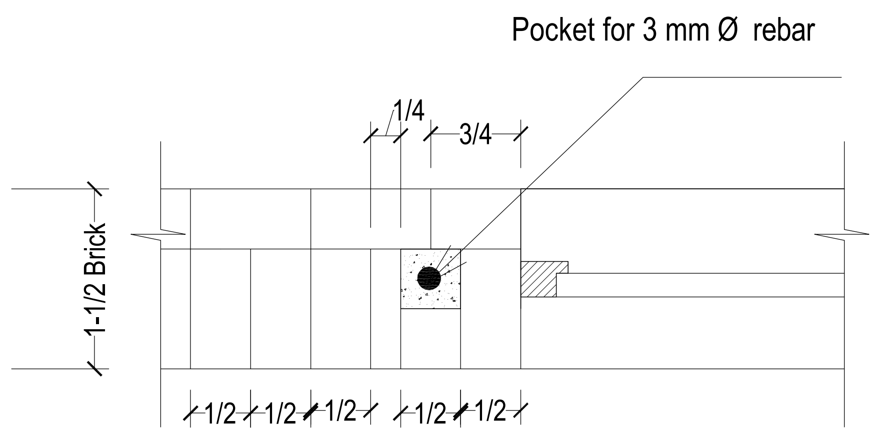


Second Layer course
(Corner Junction)

Consultant Name: University of Engineering and Technology Peshawar.	Client Name: ADB Asian Development Bank	Design Type: Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type# 3	TITLE Corner Junction Layer Courses	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad	Date: September 2018
					Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 08

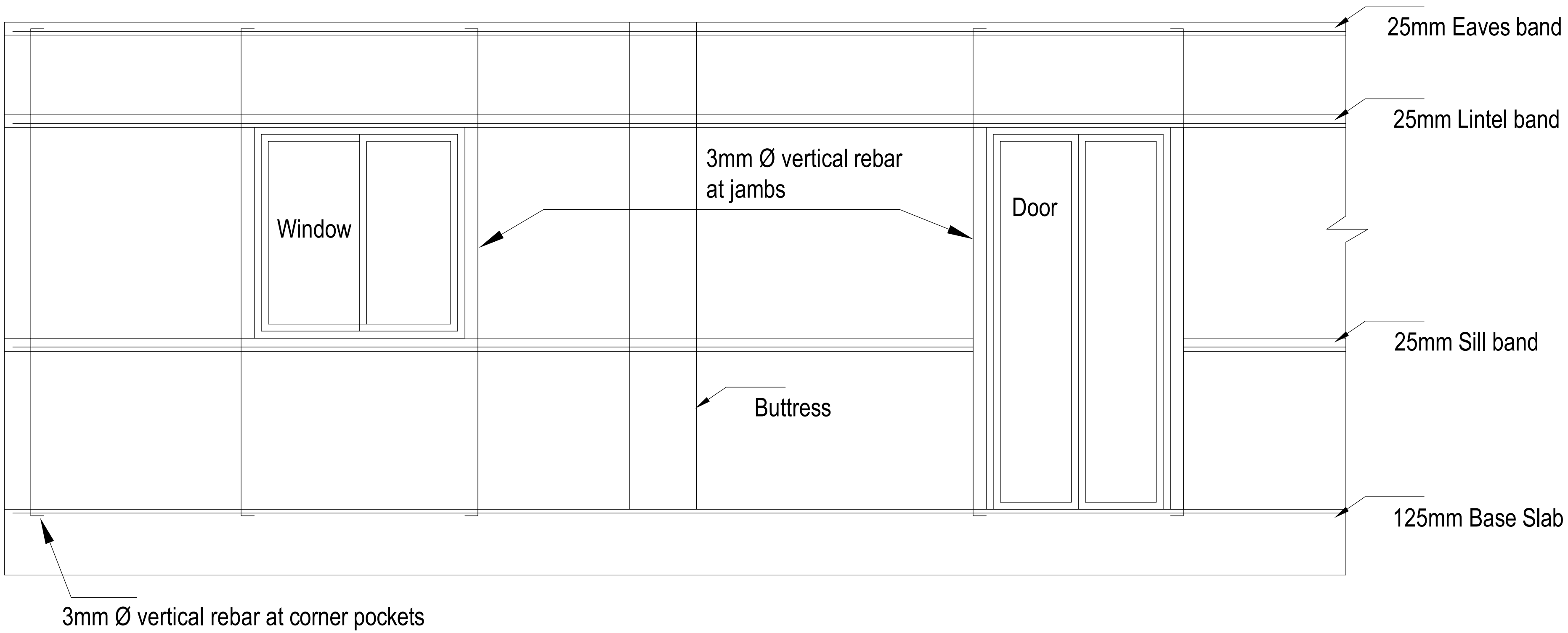


First Layer course
(Door/Window Jamb)

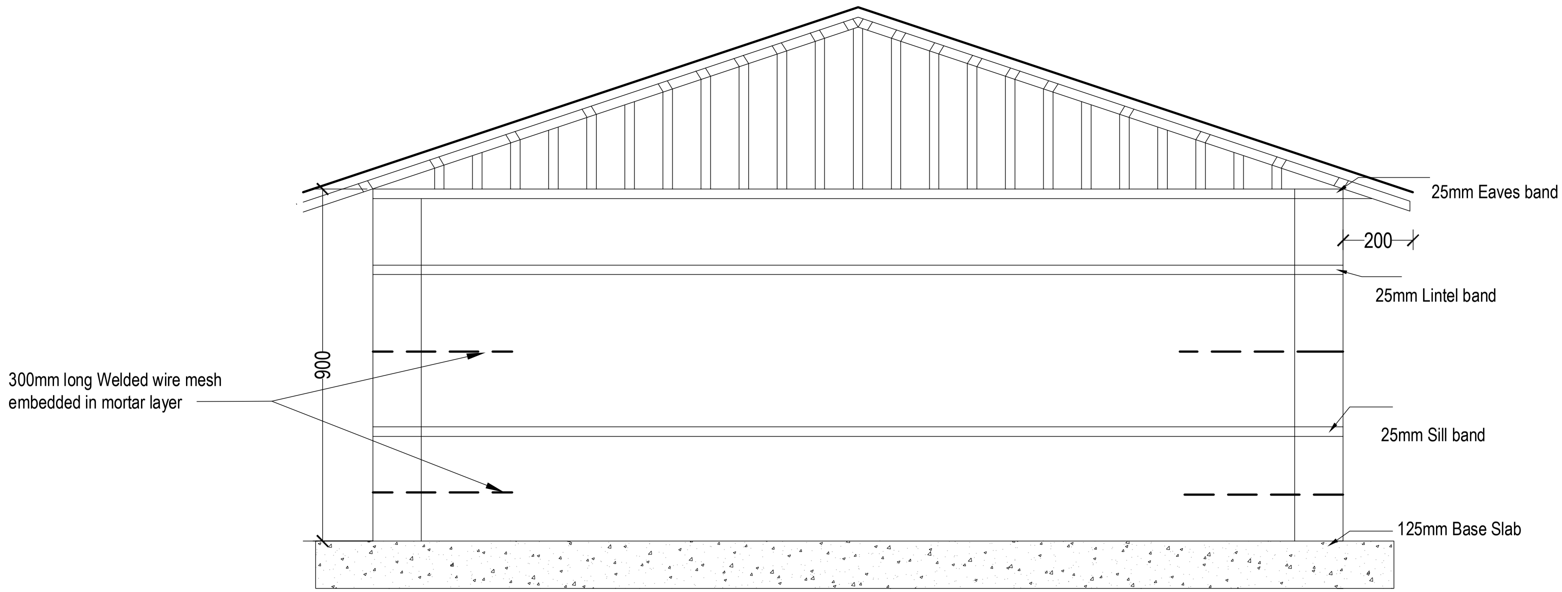


Second Layer course
(Door/Windows Jamb)

Consultant Name: University of Engineering and Technology Peshawar.	Client Name: ADB Asian Development Bank	Design Type: Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type# 3	TITLE Jamb Courses	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: September 2018 Scale: Read As Shown Dwg. No. 09

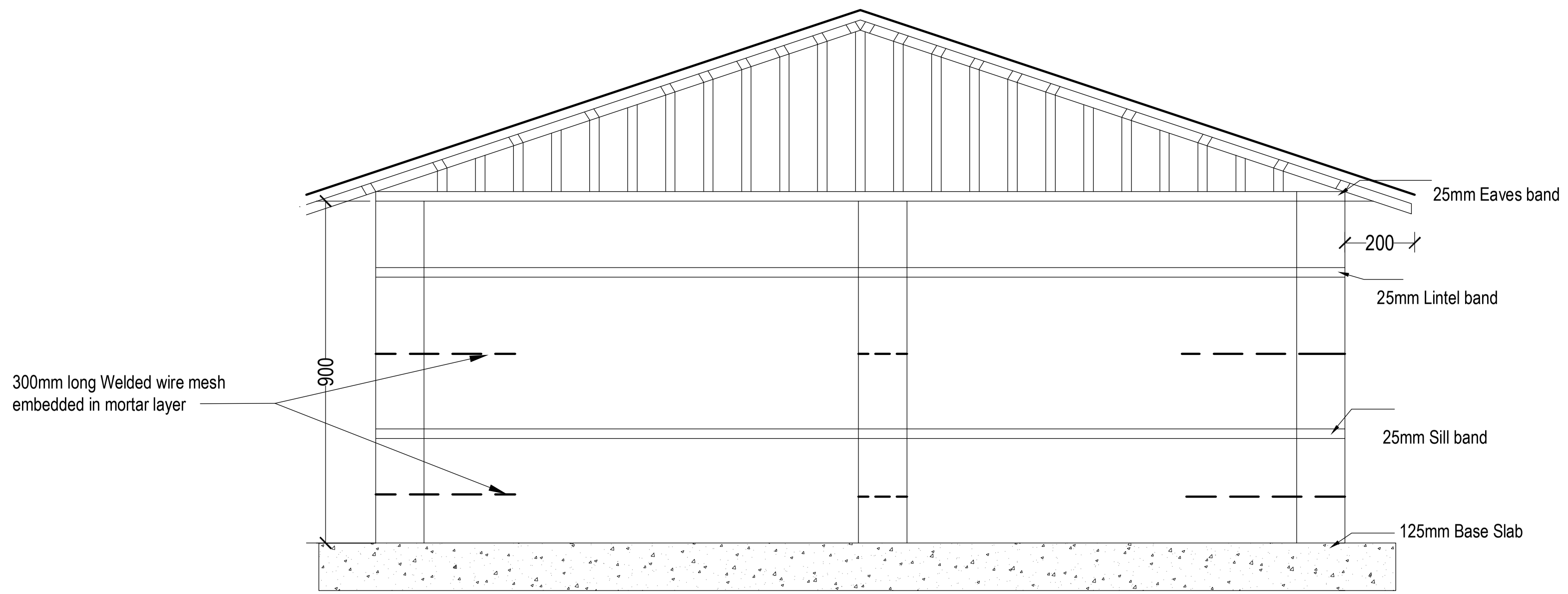


Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	ADB Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type# 3	Vertical Bars at Jamb Courses	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 10



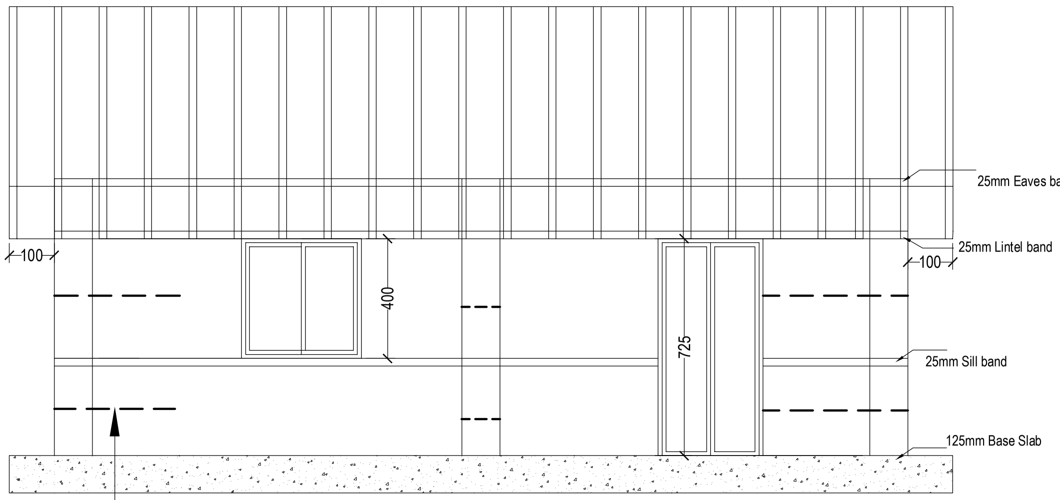
Side Elevation (W4)

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	ADB Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type# 3	Side Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 11

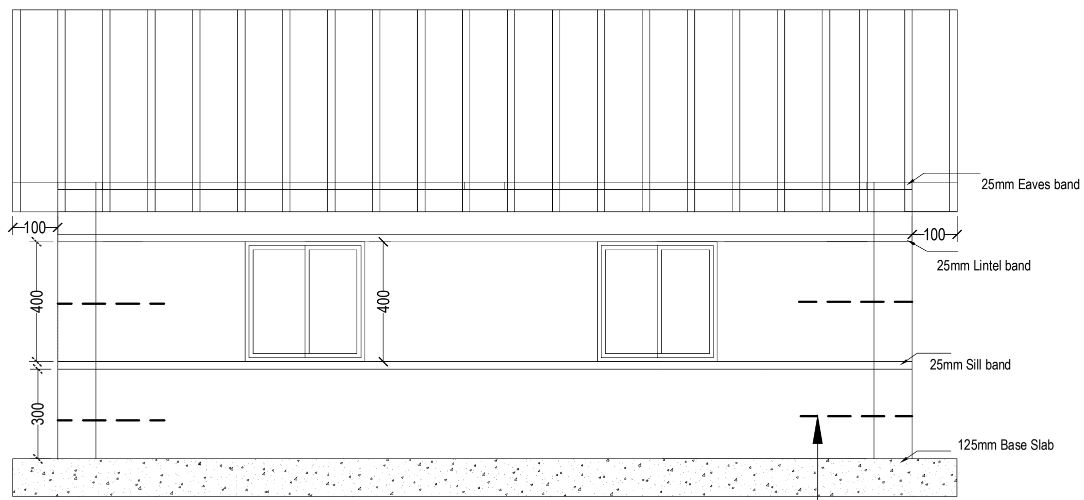


Side Elevation (W3)

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type# 3	Side Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 12



Front Elevation



Back Elevation

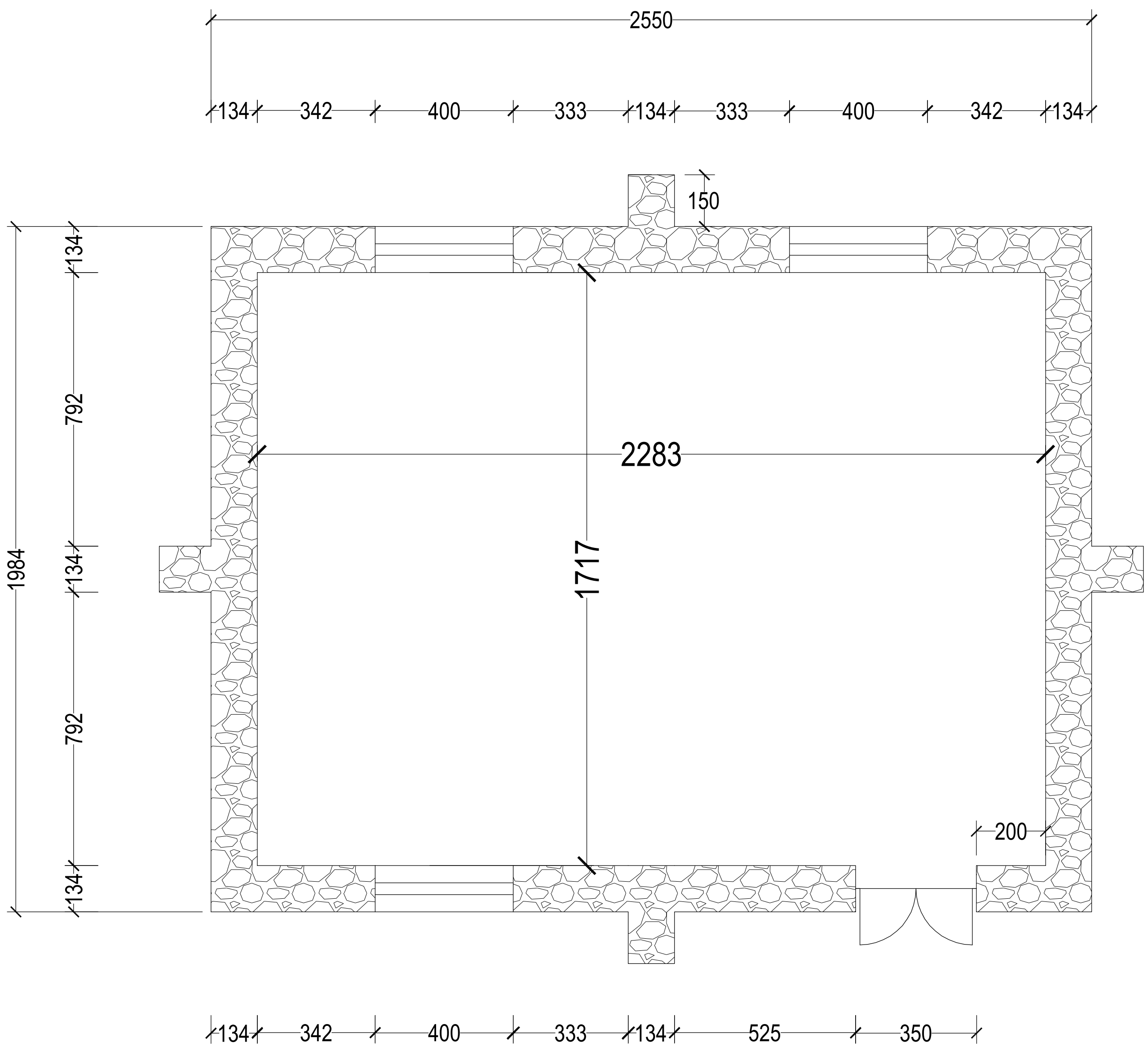
Consultant Name: University of Engineering and Technology Peshawar.	Client Name: ADB Asian Development Bank	Design Type: Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Drawings) Type# 3	TITLE Front and Back Elevation	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: September 2018 Scale: Read As Shown Dwg. No. 13

Appendix D4 – School Design Detailed Drawings-1/3rd Scale Model (Type Design 4)

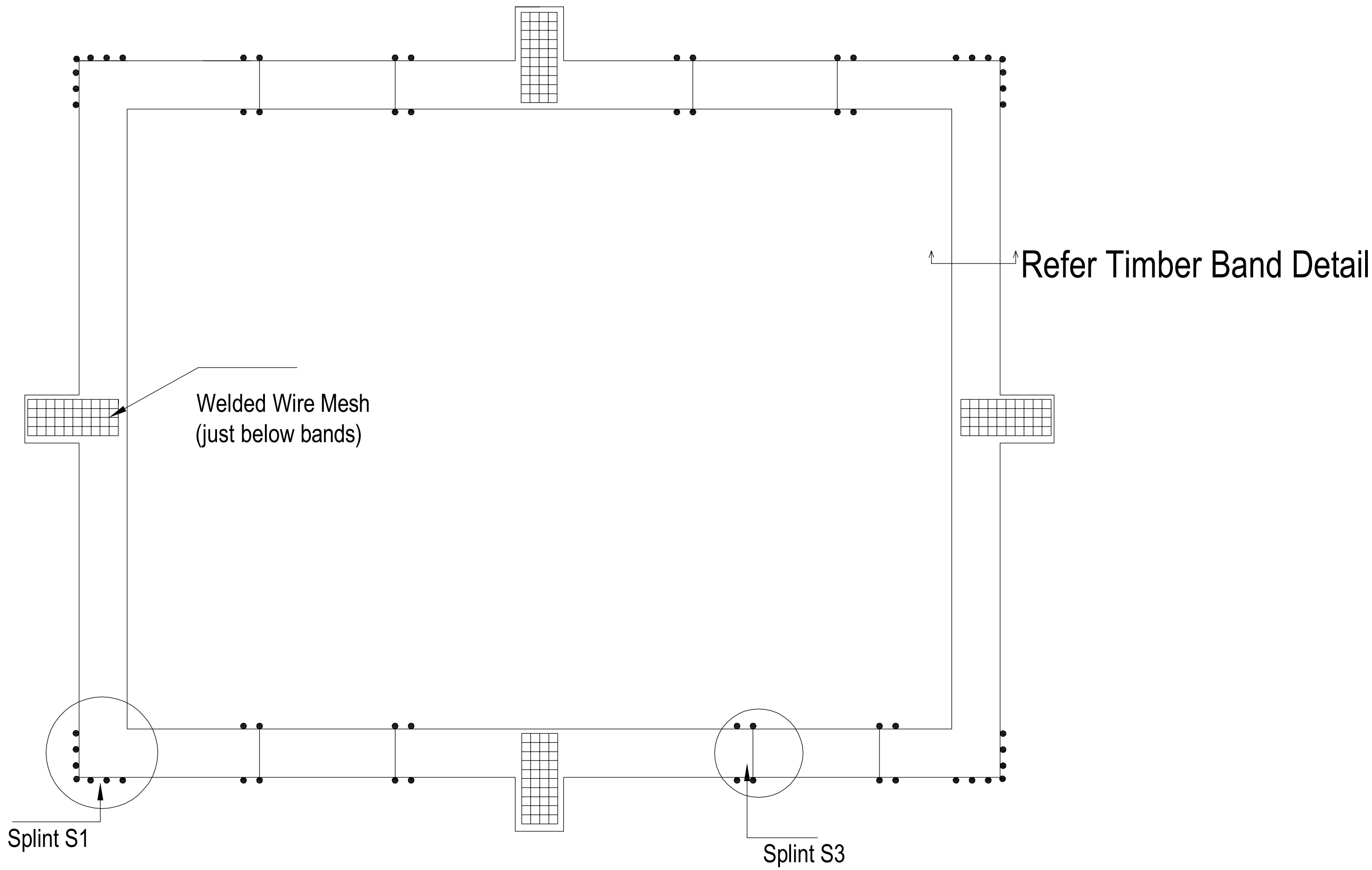
Proposed One-Third Scale Drawings of Semi-Dressed Stone Masonry with Timber Bands and Wire Containment

Type 4

Asian Development Bank



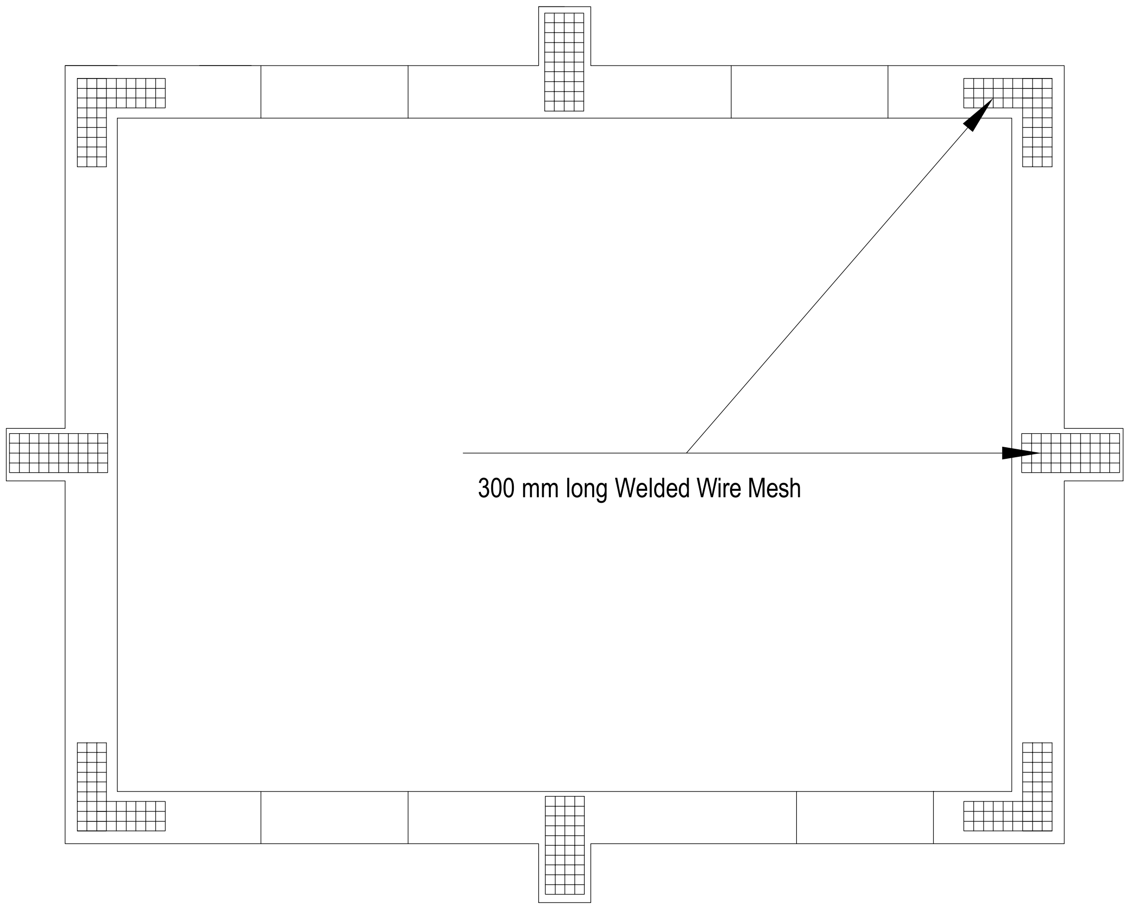
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (One Third Scale Drawings) Type# 4	FLOOR PLAN	Dr. Qaisar Ali Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: September 2018 Scale: Read As Shown Dwg. No. 01



- Containment wires not shown for clarity.
- Plinth band not provided.
- Wires shown for splints are representative only.

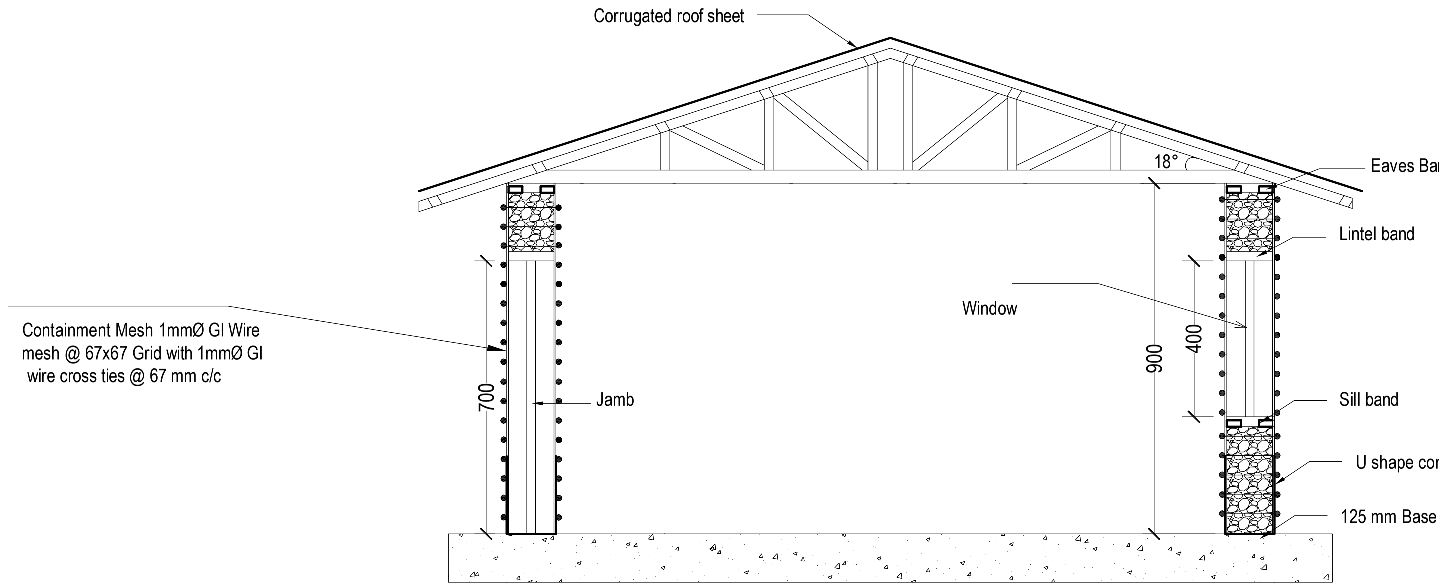
- Provide Buttress Stitches at
  > Plinth, Sill, Lintel and Eaves Level.
  > Between Plinth and Sill.
  > Between Lintel and Eaves Level.

Consultant Name: University of Engineering and Technology Peshawar.	Client Name: Asian Development Bank	Design Type: Semidressed Stone Masonry with Timber Bands and wire containment (One Third Scale Drawings) Type# 4	TITLE Band, Vertical Wires at Wall-Junctions, Jambs and Butresses Stitches	Researchers: Dr. Qaisar Ali Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: September 2018 Scale: Read As Shown Dwg. No. 02



- Welded Wire Mesh (WWM) placed midway between
    1. DPC and Sill Level, and
    2. Sill and Lintel Level.
- WWM embedded in mortar layer.
- Splints S1 and S3 not shown for clarity.

Consultant Name: University of Engineering and Technology Peshawar.	Client Name: Asian Development Bank	Design Type: Semidressed Stone Masonry with Timber Bands and wire containment (One Third Scale Drawings) Type# 4	TITLE: Stitch Detail	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad	Date: September 2018
				Drafted by: Engr. Attaur Rahman	Scale: Read As Shown
					Dwg. No. 03

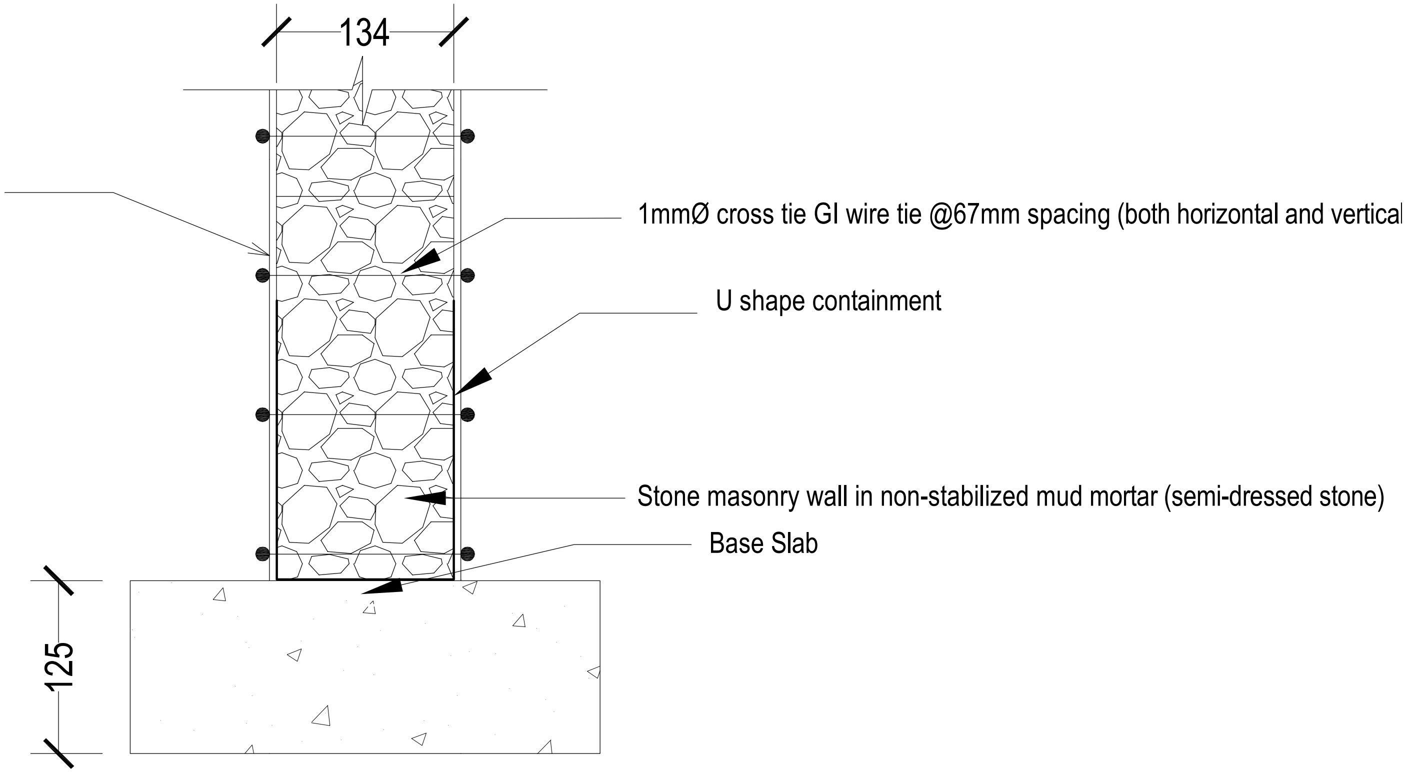


Note:

1. The vertical wires are connected to sill, lintel and eaves band by wrapping it around a nail and then hammered.
2. At eaves band, the vertical wires from both the interior and exterior faces connects at top of the eaves band and hence intertwined.
3. Containment Wires in the shape of U is placed below the first course and then it is intertwined with the vertical containment.
   U shape is shown as bold lines in the drawing.

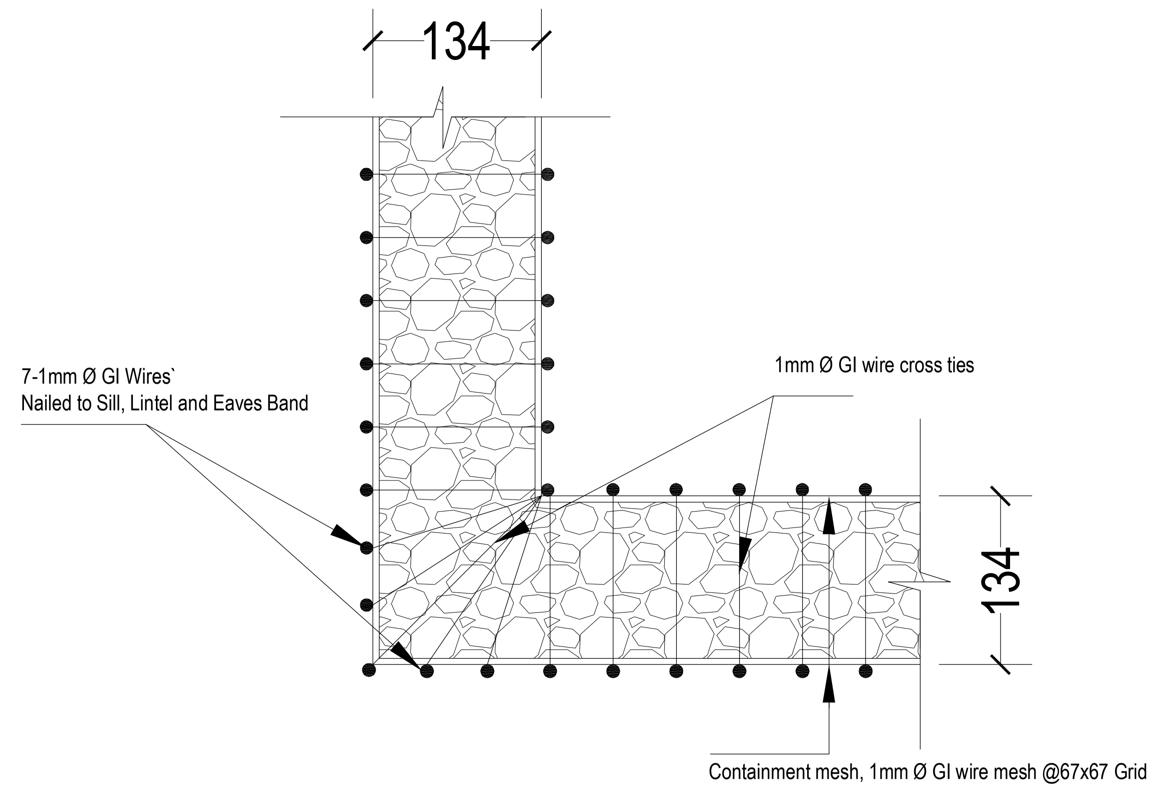
Levels	
Ridge Level	+1347 mm
CeilingLevel	+900 mm
Lintel Level	+700 mm
Sill Level	+300 mm
Base Slab Level	+00 mm

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (One Third Scale Drawings) Type# 4	Structural Section	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 04



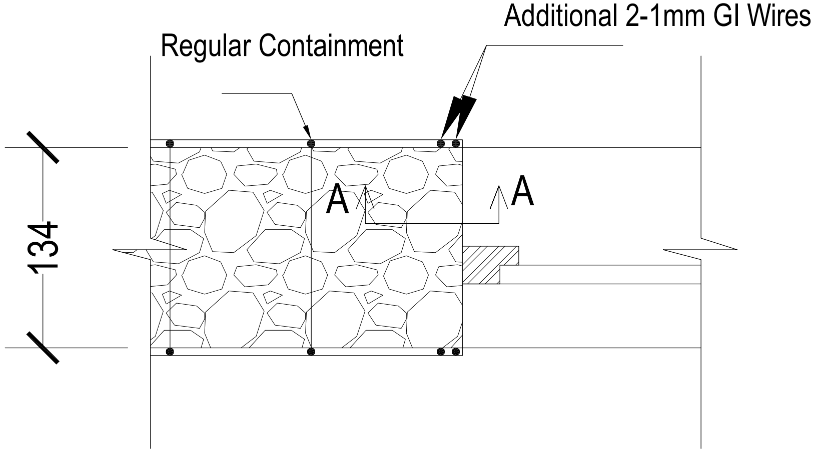
Wall Section

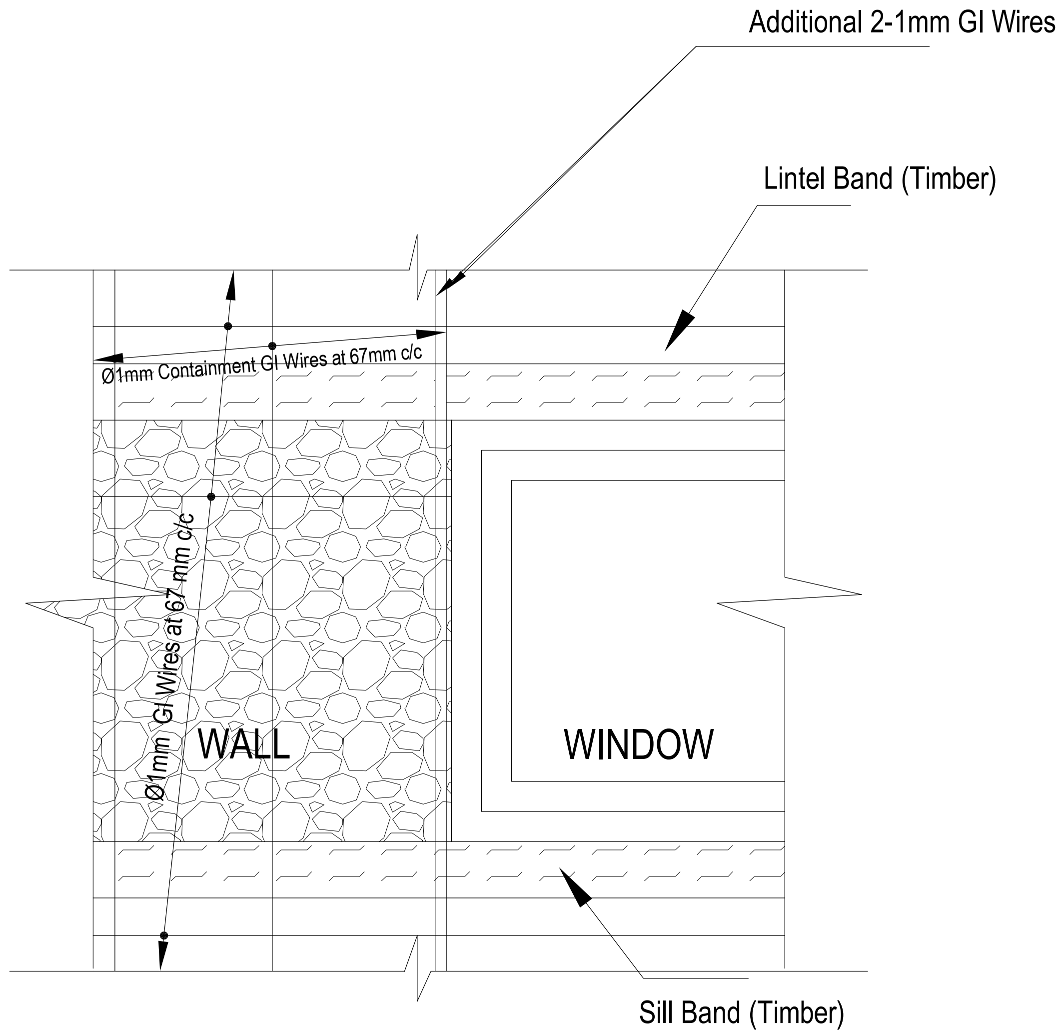
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (One Third Scale Drawings) Type# 4	Wall Section Detail	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 05



Corner Splint S1

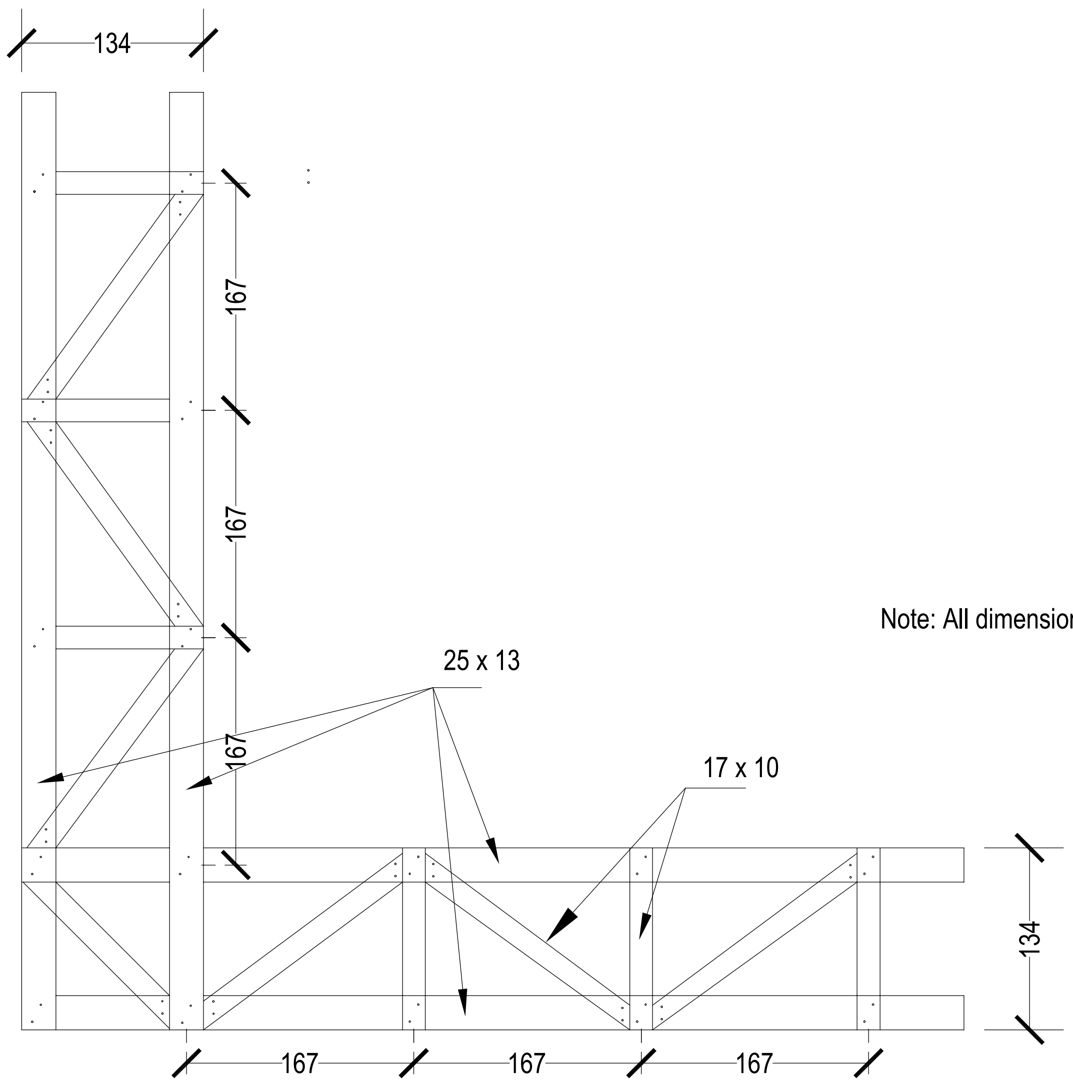
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (One Third Scale Drawings) Type# 4	Corner Splint S1 Detail	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 06





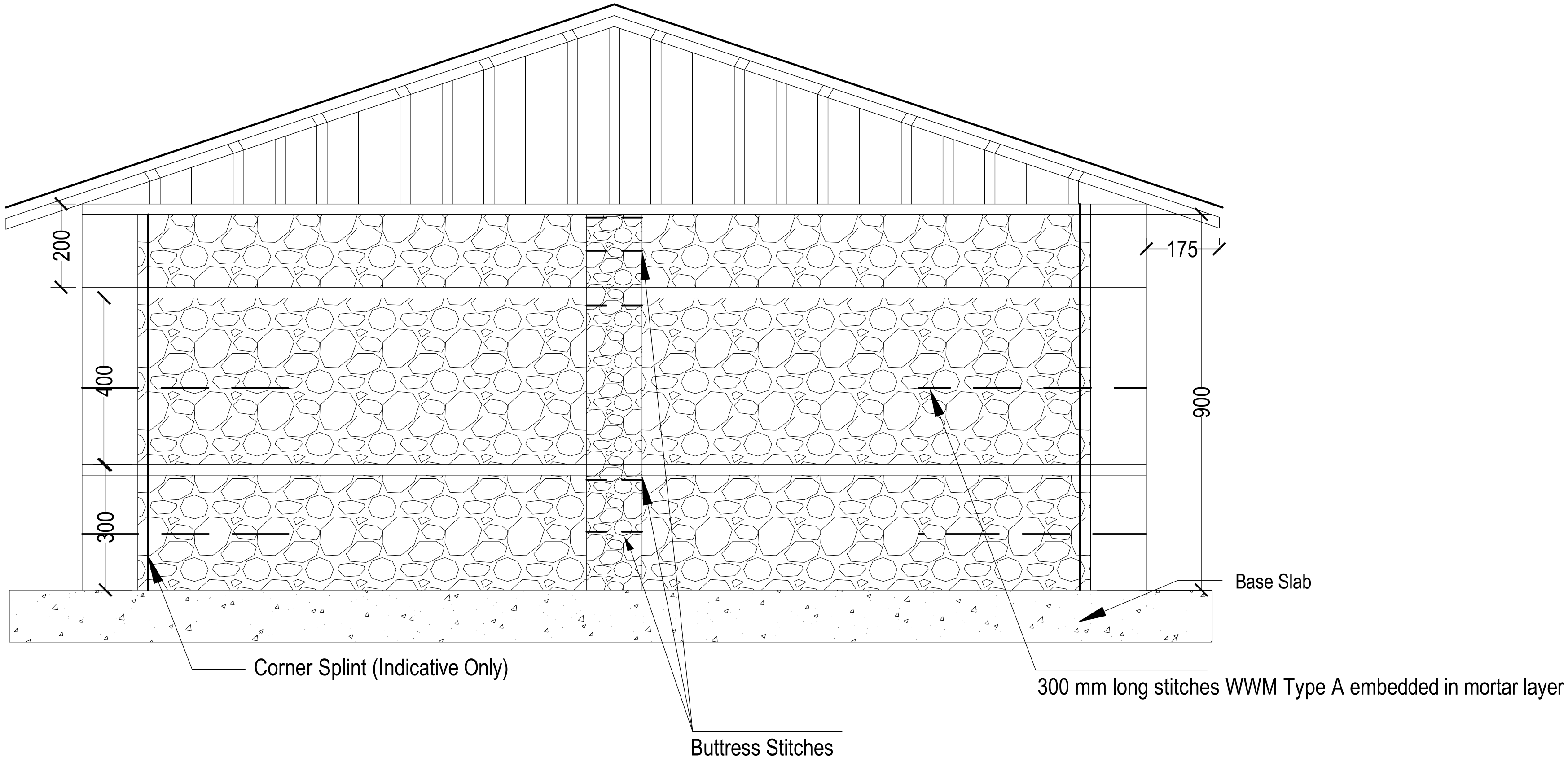
Section at A-A

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (One Third Scale Drawings) Type# 4	Jamb Splint S3 Detail	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 07



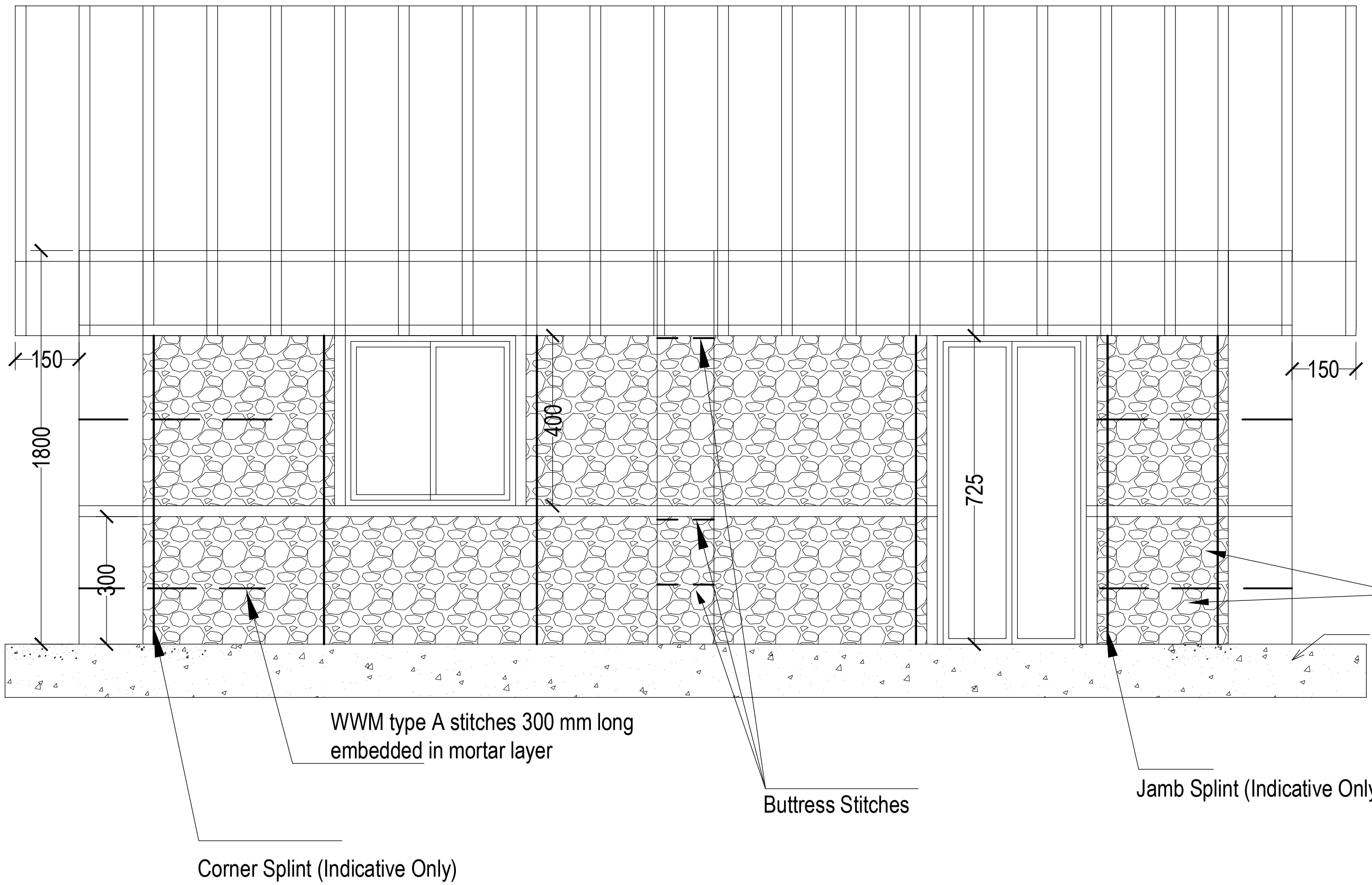
Note: All dimensions are in mm

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (One Third Scale Drawings) Type# 4	Lintel Band Detail Sill Band Detail Eaves Band Detail	Dr. Qaisar Ali Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: September 2018 Scale: Read As Shown Dwg. No. 08



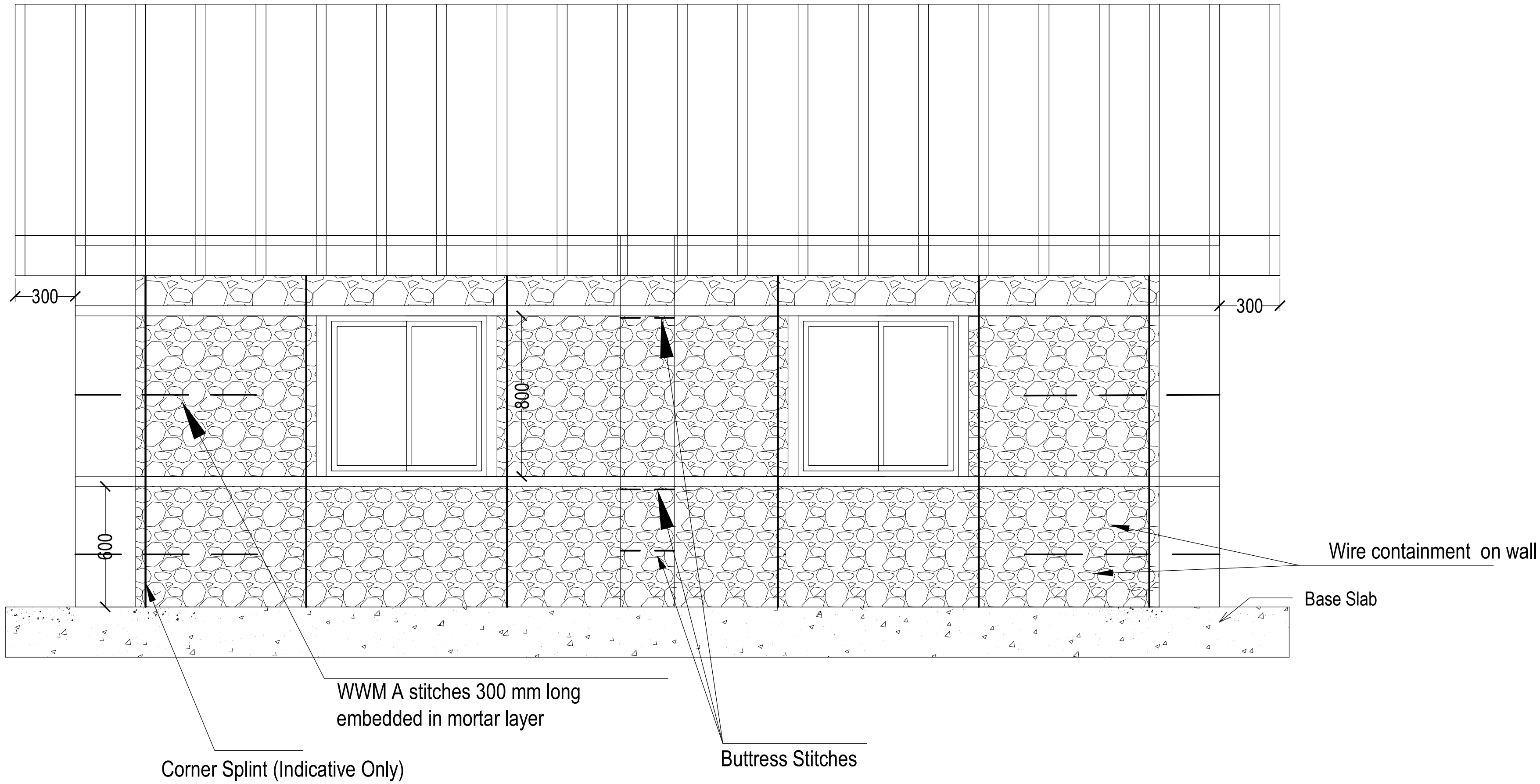
Side Elevation

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (One Third Scale Drawings) Type# 4	Side Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 09



Front Elevation

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (One Third Scale Drawings) Type# 4	Front Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 10

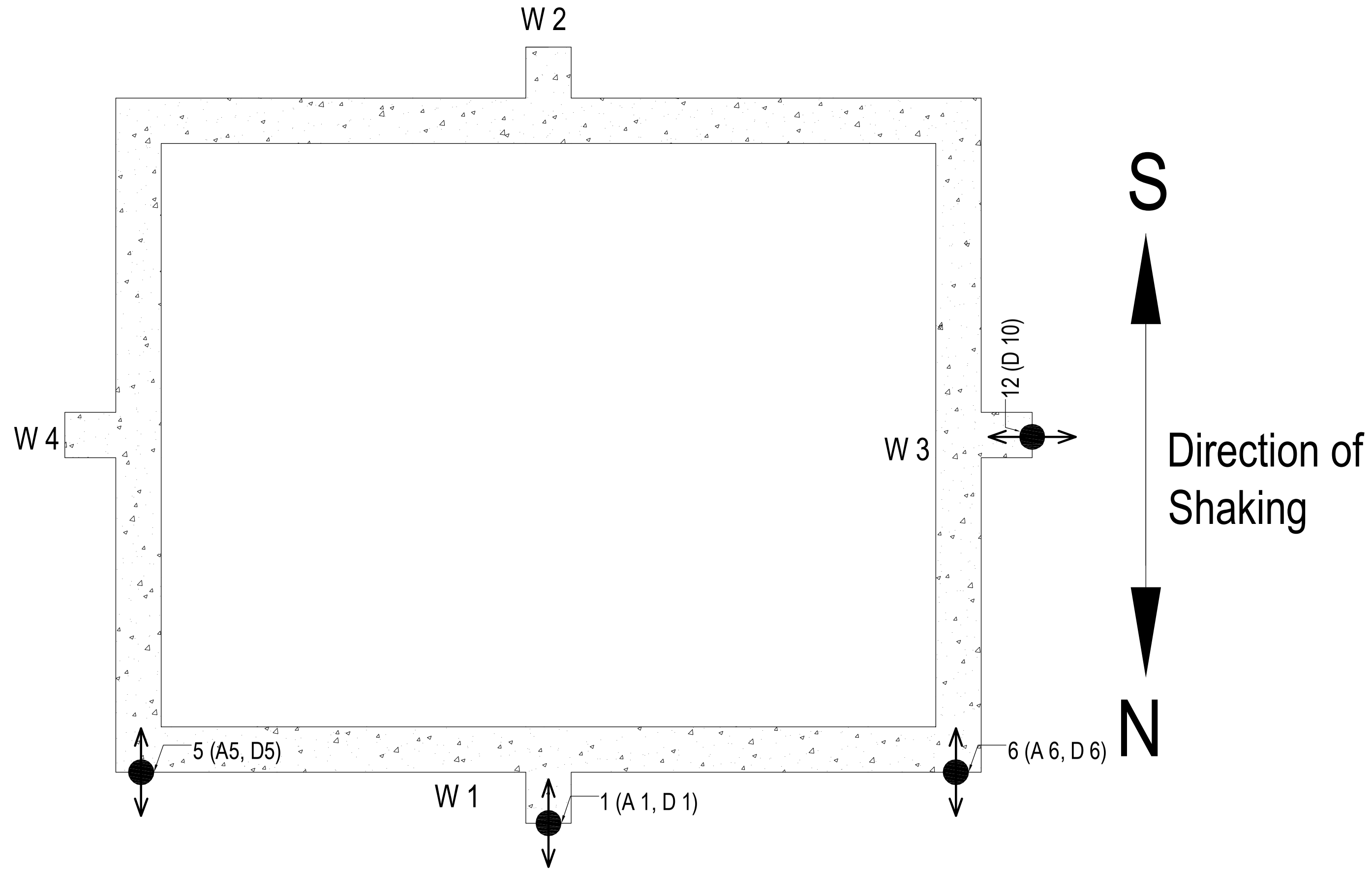


Back Elevation

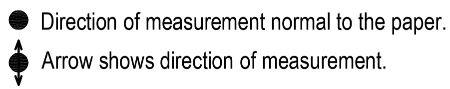
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands and wire containment (One Third Scale Drawings) Type# 4	Back Elevation	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 11

Appendix E1– Instrumentation Plan for 2/3rd Scale Model

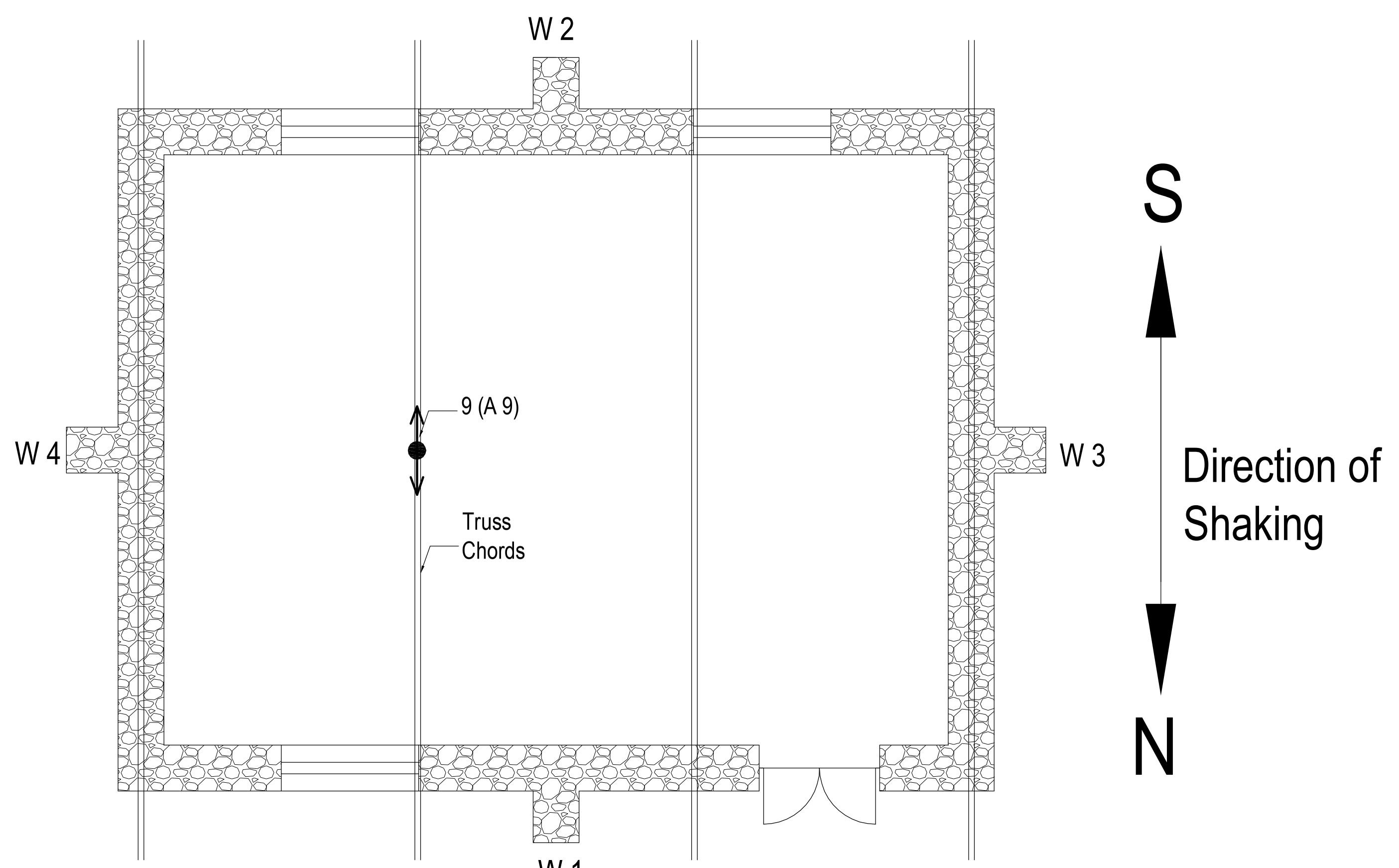
(Type Design 1)



Ground Floor
Plan



Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry in Cement Stabilized Mud Mortar and RCC Bands (Two Third Scale Model) Type # 1	Instrumentation Plan - Ground Floor Plan	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 01

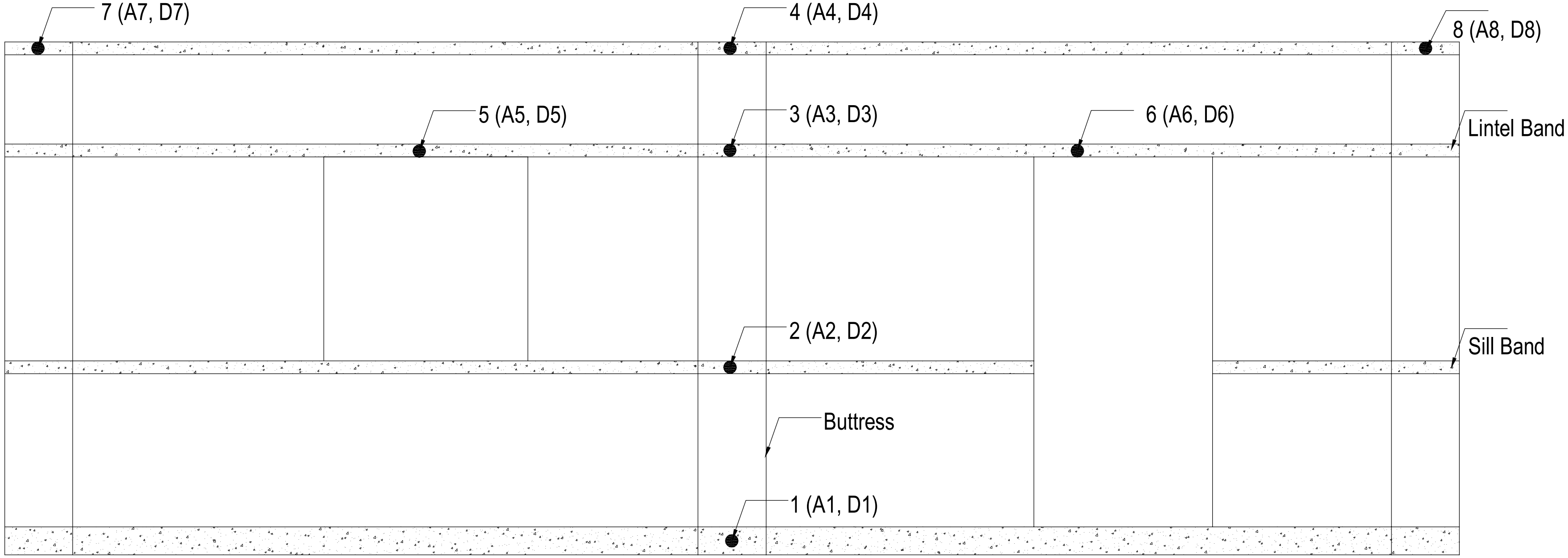


Plan View

● Direction of measurement normal to the paper.

↕ Arrow shows direction of measurement.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	ADB Asian Development Bank	Semidressed Stone Masonry in Cement Stabilized Mud Mortar and RCC Bands (Two Third Scale Model) Type # 1	Instrumentation Plan - Eaves Level Plan	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 02

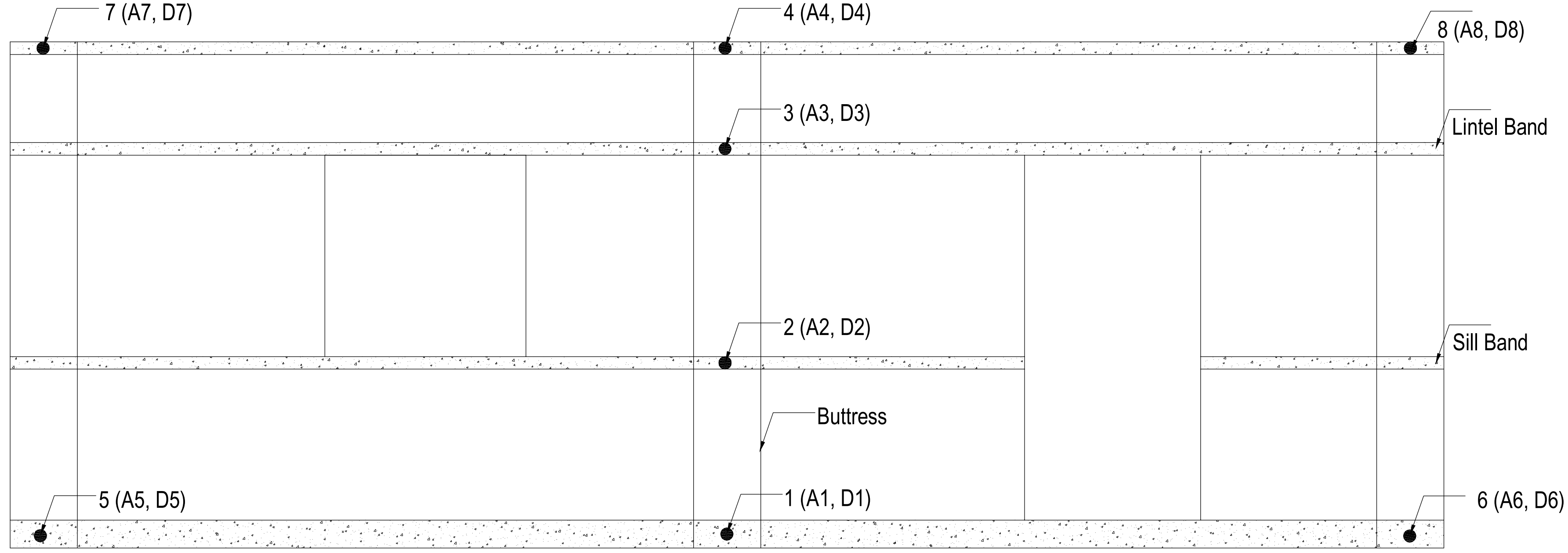


Front Wall Elevation
(Wall 1)

● Direction of measurement normal to the paper.

↕ Arrow shows direction of measurement.

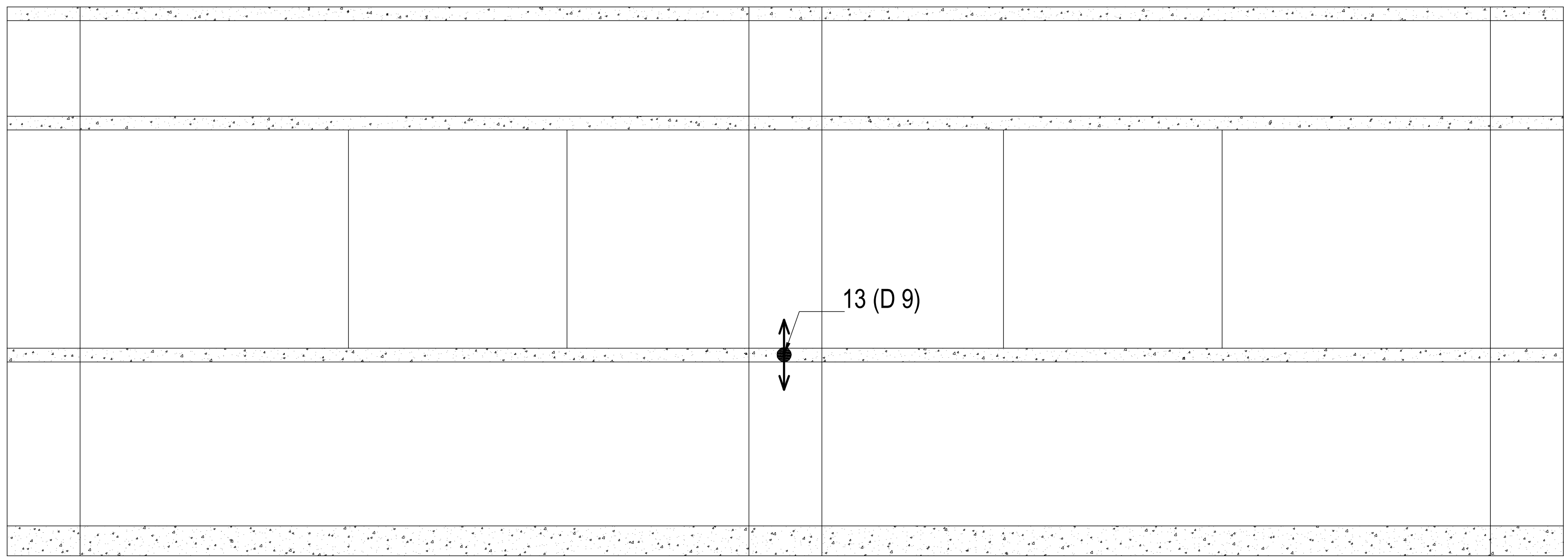
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry in Cement Stabilized Mud Mortar and RCC Bands (Two Third Scale Model) Type # 1	Instrumentation Plan - Wall 1 (B)	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 03



Front Wall Elevation
(Wall 1)

- Direction of measurement normal to the paper.
- Arrow shows direction of measurement.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry in Cement Stabilized Mud Mortar and RCC Bands (Two Third Scale Model) Type # 1	Instrumentation Plan - Wall 1 (B)	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 04

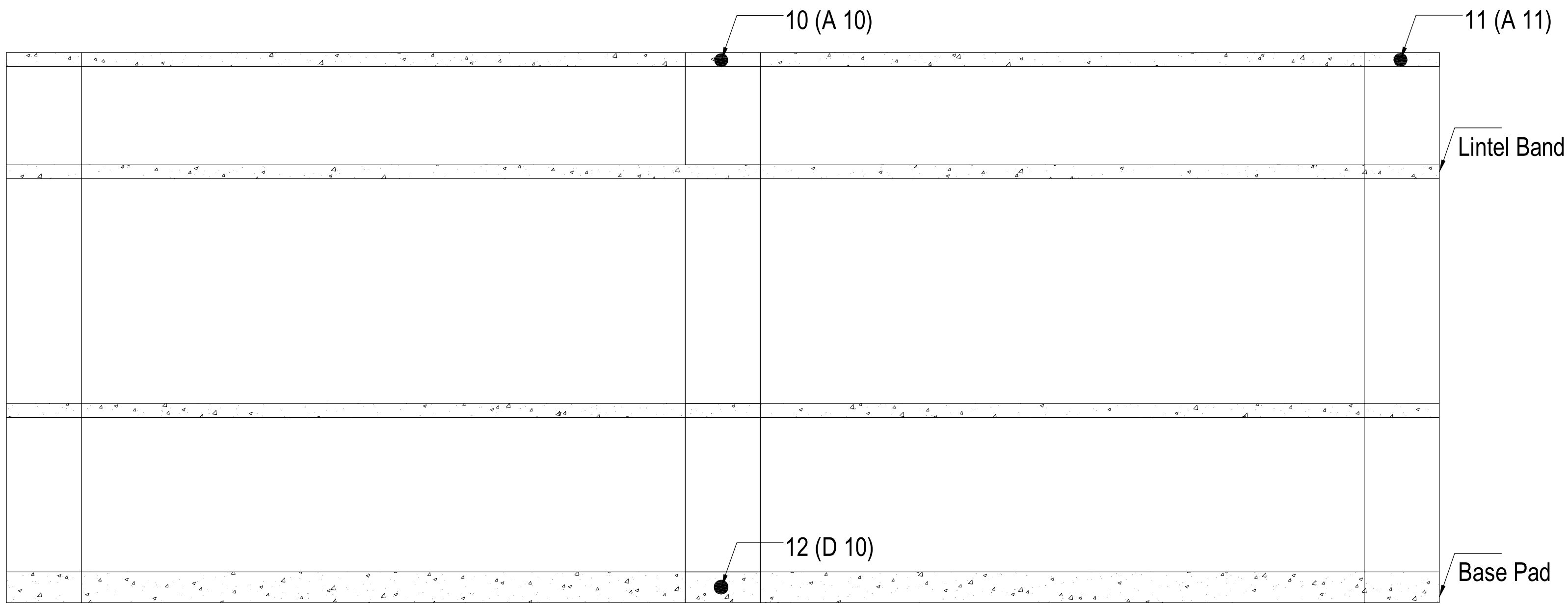


Back Wall Elevation
(Wall 2)

● Direction of measurement normal to the paper.

Arrow shows direction of measurement.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry in Cement Stabilized Mud Mortar and RCC Bands (Two Third Scale Model) Type # 1	Instrumentation Plan - Wall 2	Dr. Qaisar Ali, Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 05



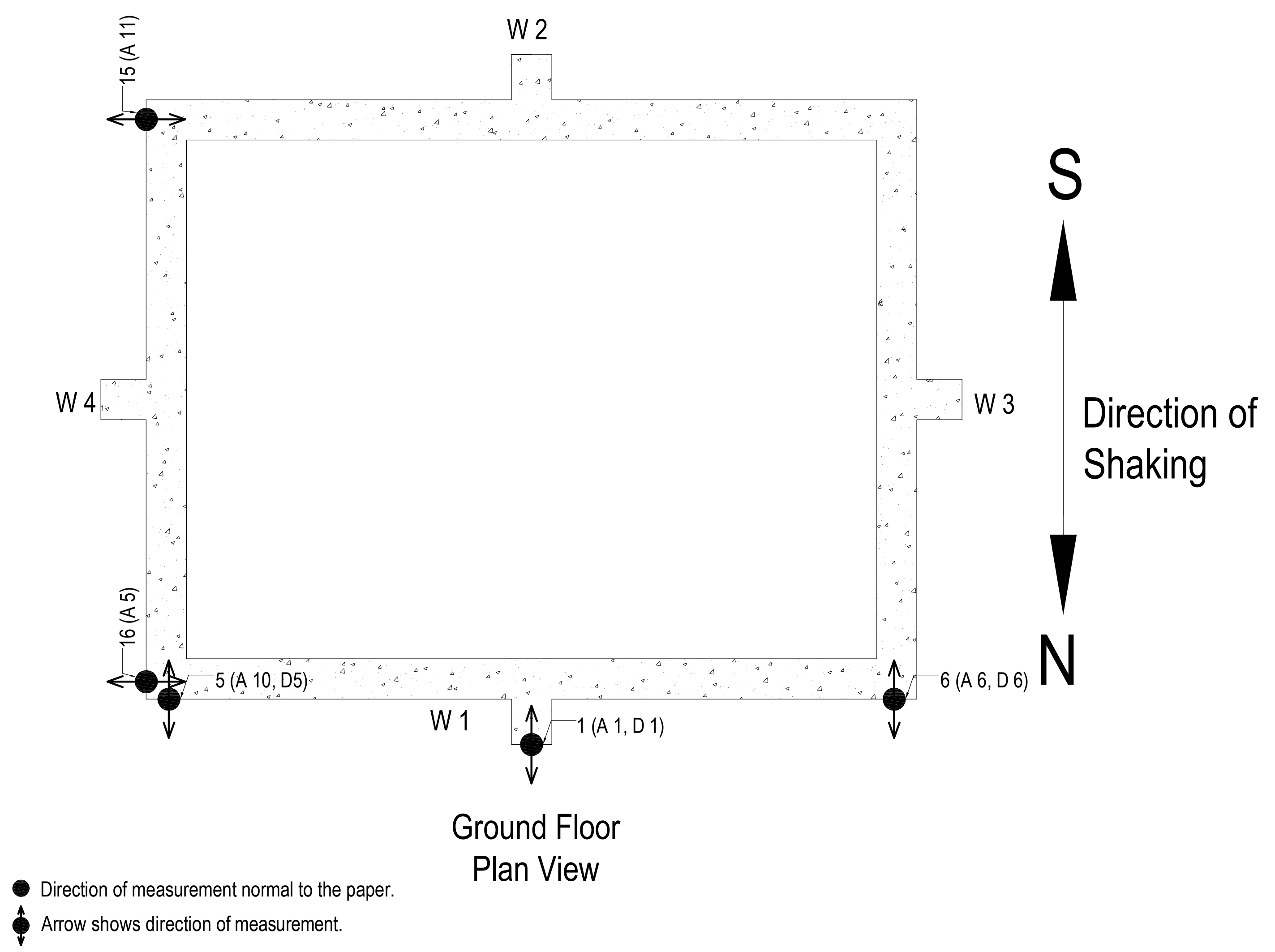
Side Elevation
(Wall 3)

- Direction of measurement normal to the paper.
- Arrow shows direction of measurement.

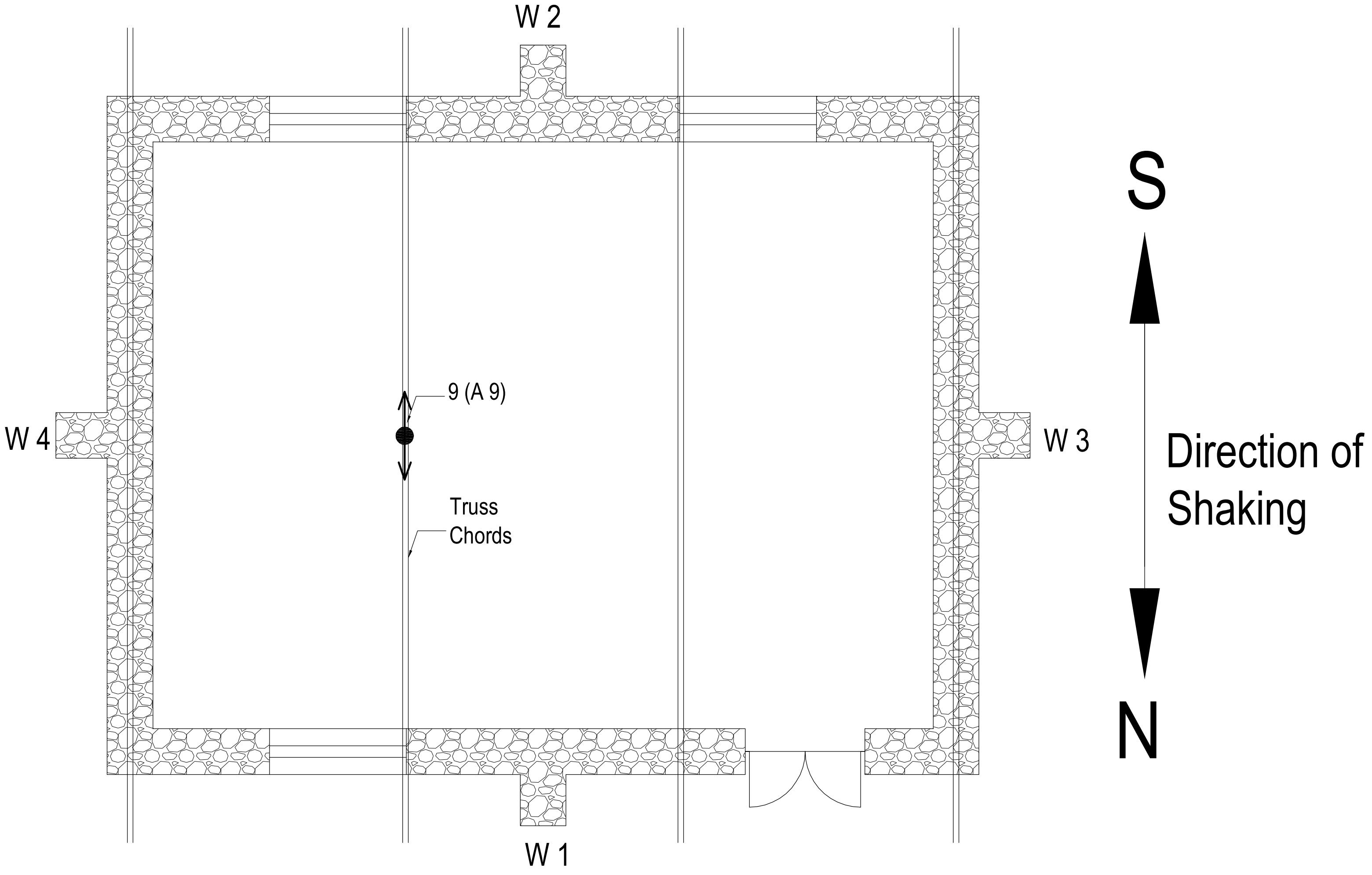
Consultant Name: University of Engineering and Technology Peshawar.	Client Name: ADB Asian Development Bank	Design Type: Semidressed Stone Masonry in Cement Stabilized Mud Mortar and RCC Bands (Two Third Scale Model) Type # 1	TITLE Instrumentation Plan - Wall 3	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad	Date: September 2018
					Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 06

Appendix E2– Instrumentation Plan for 2/3rd Scale Model

(Type Design 2)



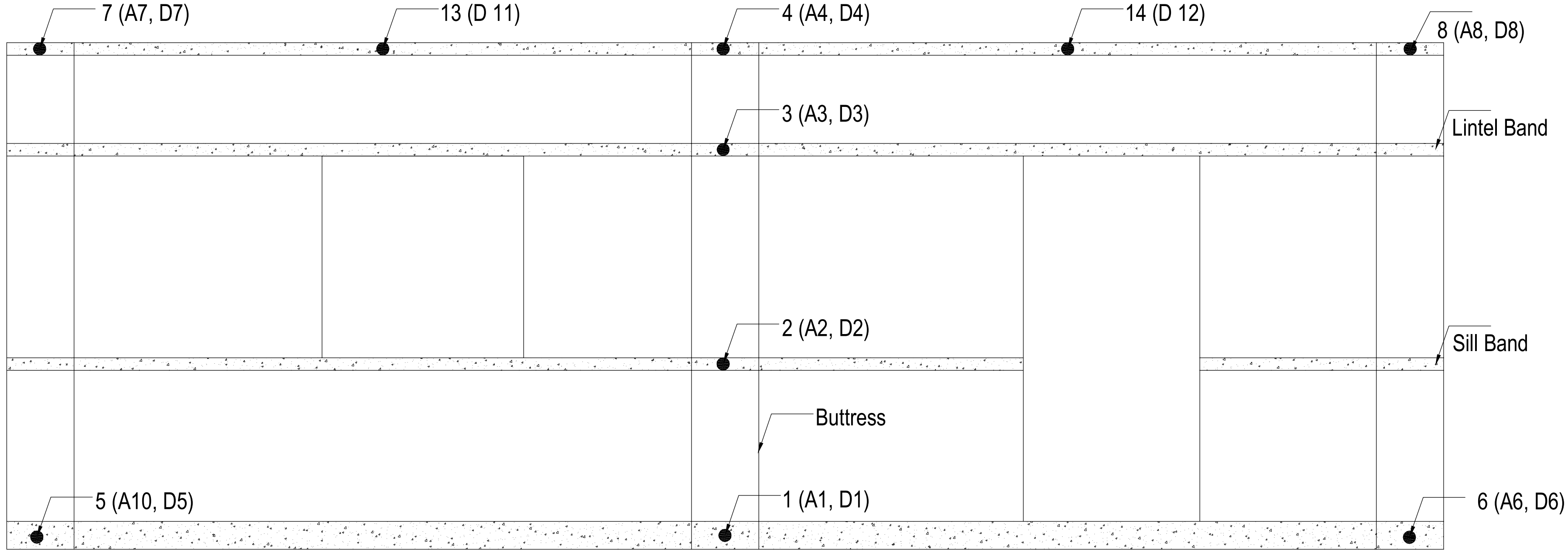
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabian Mesh/ Geogrid Bands & Wire Containment (Type 2 Two Third Scale Model)	Instrumentation Plan Ground Floor Plan View	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 01



Plan View

- Direction of measurement normal to the paper.
- Arrow shows direction of measurement.

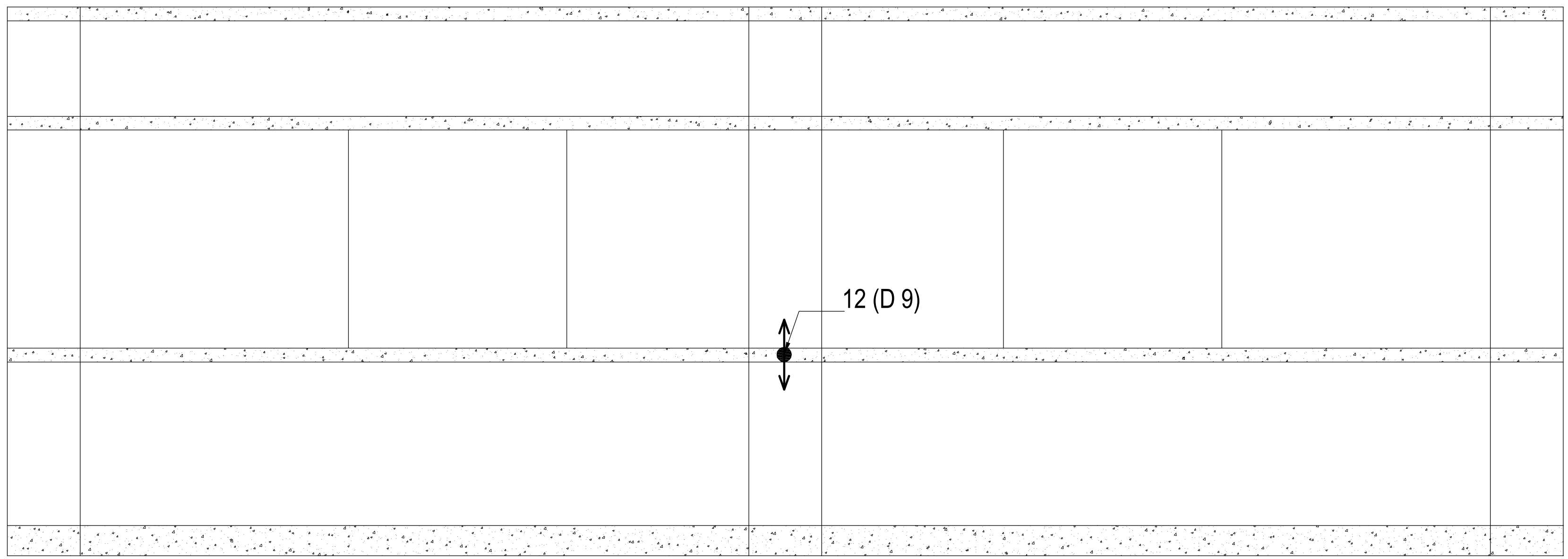
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabian Mesh/ Geogrid Bands & Wire Containment (Type 2 Two Third Scale Model)	Instrumentation Plan Eaves Level Plan	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 02



Front Wall Elevation
(Wall 1)

- ● Direction of measurement normal to the paper.
- Arrow shows direction of measurement.

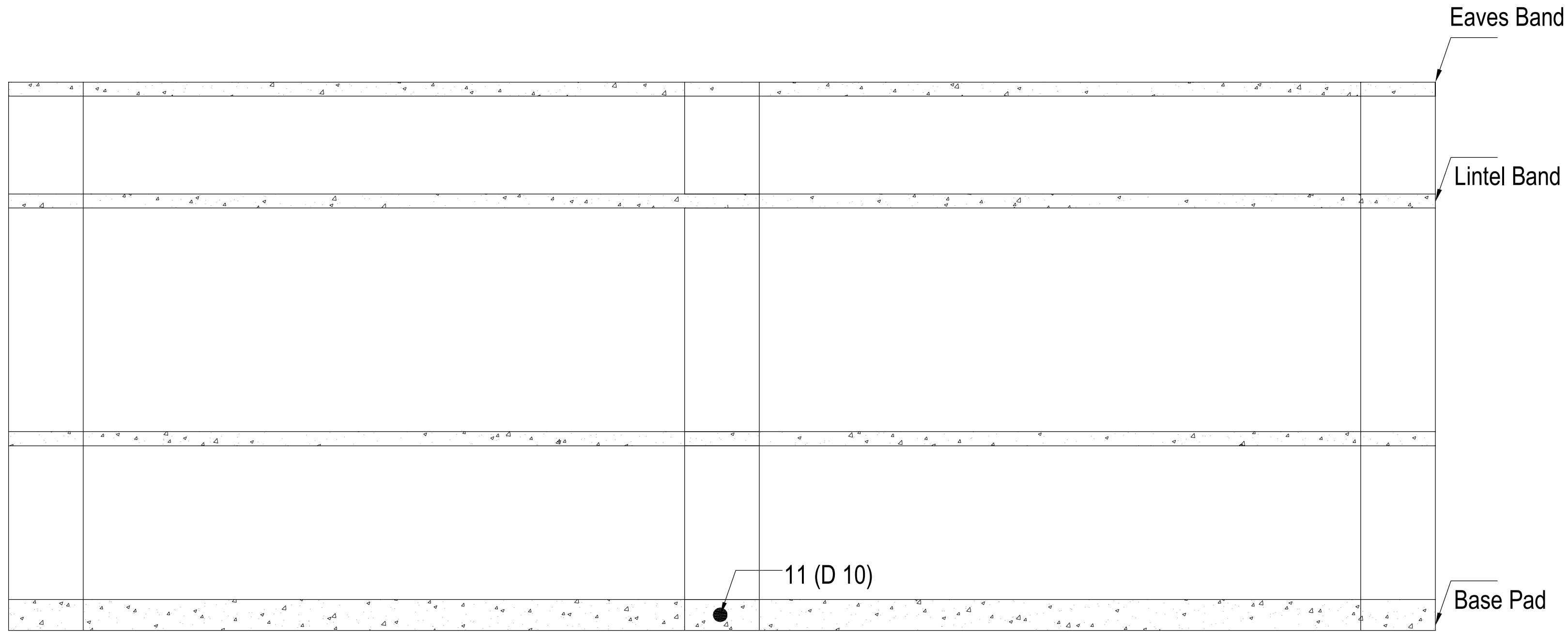
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabian Mesh/ Geogrid Bands & Wire Containment (Type 2 Two Third Scale Model)	Instrumentation Plan Wall 1	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 03



Back Wall Elevation
(Wall 2)

- ● Direction of measurement normal to the paper.
- ↕ Arrow shows direction of measurement.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabian Mesh/ Geogrid Bands & Wire Containment (Type 2 Two Third Scale Model)	Instrumentation Plan Wall 2	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 04

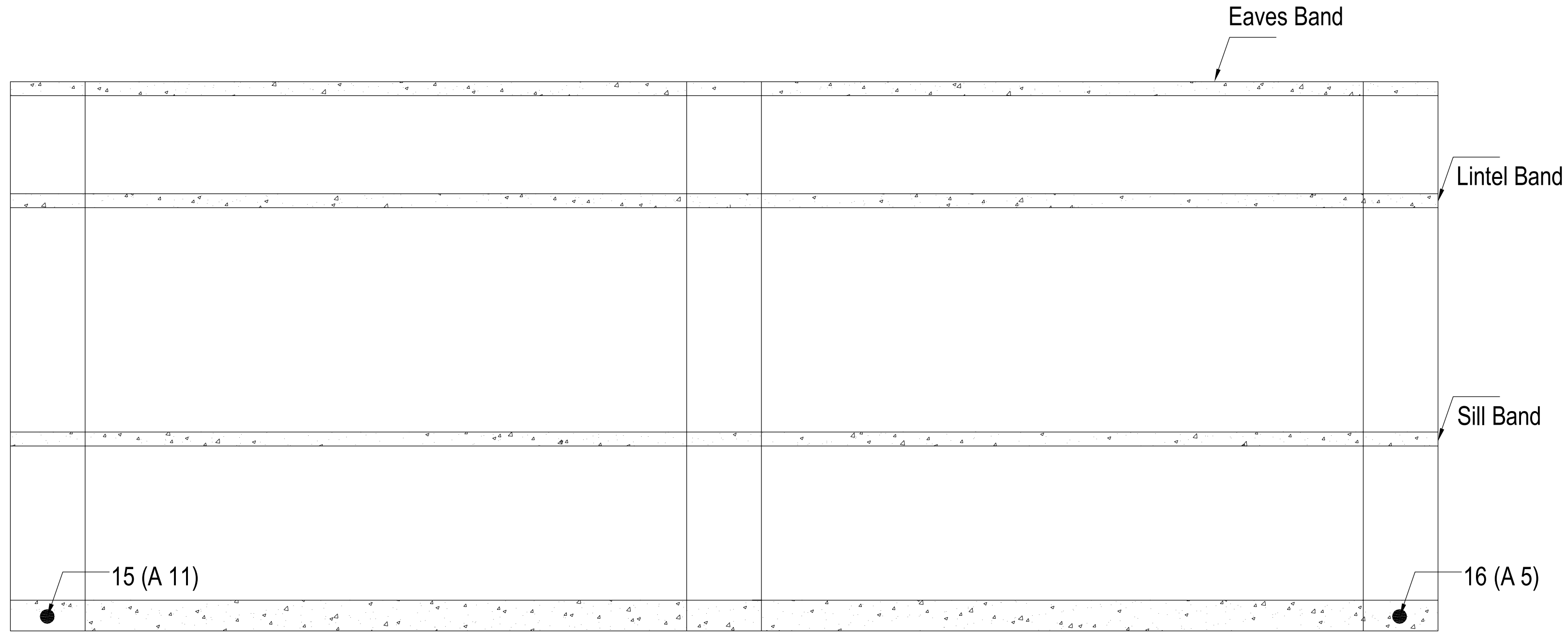


Side Elevation
(Wall 3)

Direction of measurement normal to the paper.

Arrow shows direction of measurement.

Consultant Name: University of Engineering and Technology Peshawar.	Client Name: Asian Development Bank	Design Type: Semidressed Stone Masonry with Gabian Mesh/ Geogrid Bands & Wire Containment (Type 2 Two Third Scale Model)	TITLE Instrumentation Plan Wall 3	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: September 2018 Scale: Read As Shown Dwg. No. 05



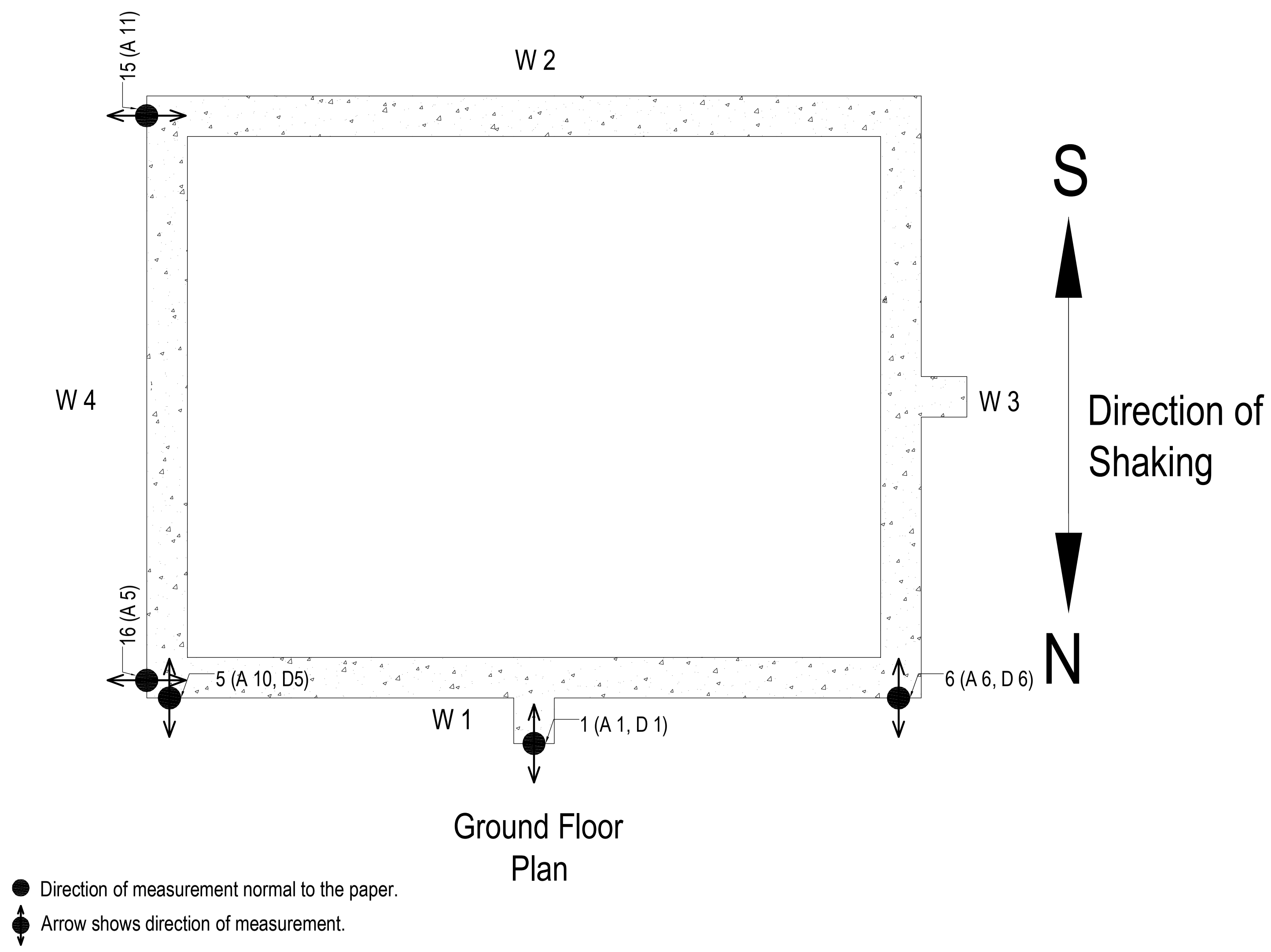
Side Elevation
(Wall 4)

- Direction of measurement normal to the paper.
- Arrow shows direction of measurement.

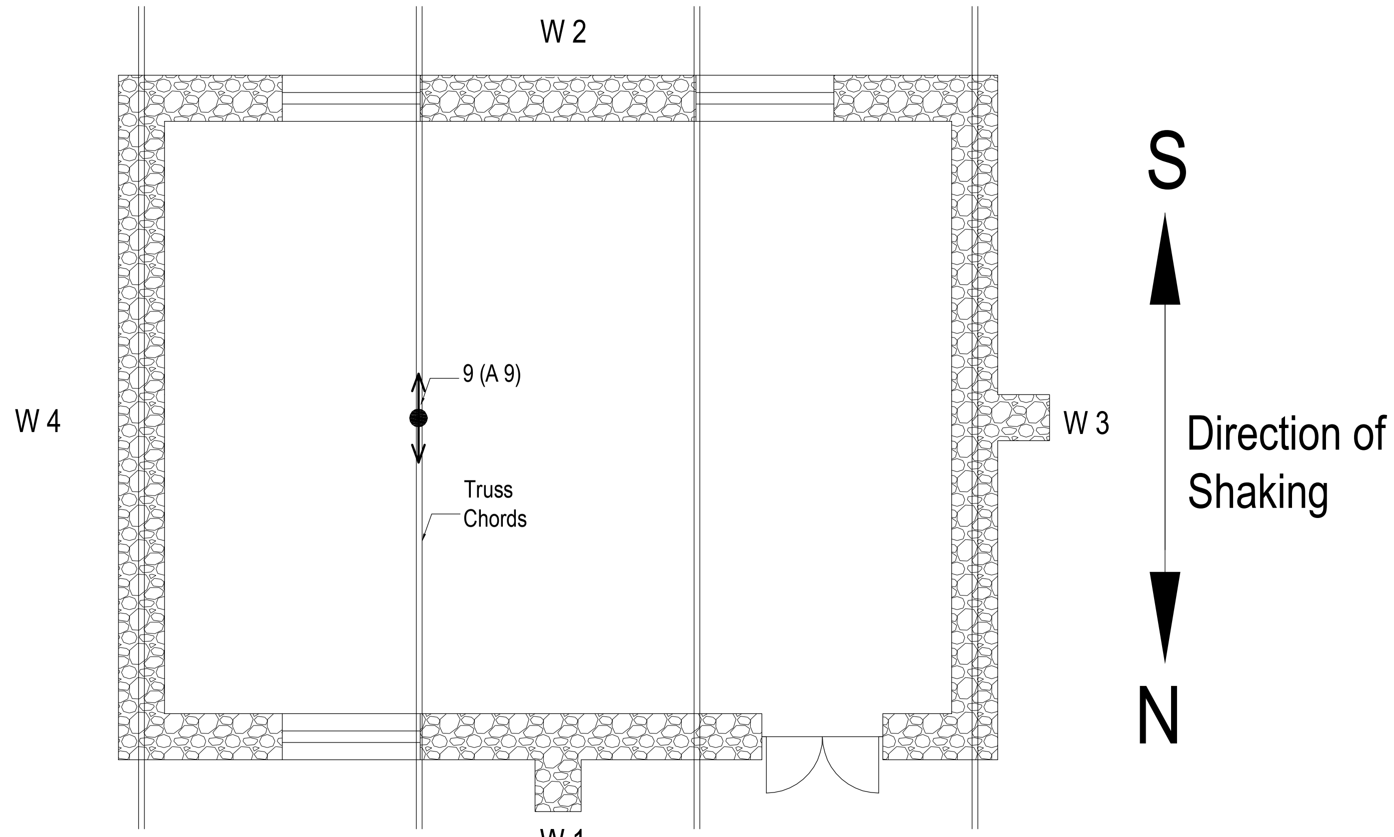
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabian Mesh/ Geogrid Bands & Wire Containment (Type 2 Two Third Scale Model)	Instrumentation Plan Wall 4	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 06

Appendix E3– Instrumentation Plan for 2/3rd Scale Model

(Type Design 3)



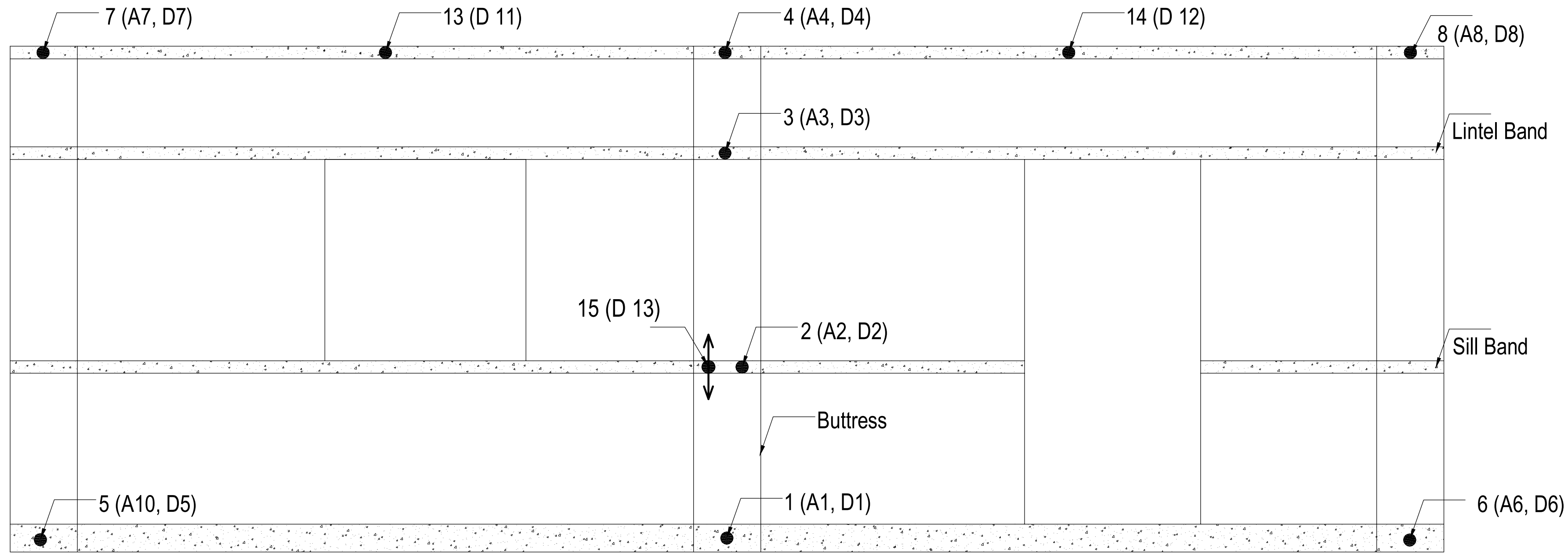
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Model) Type # 3	Instrumentation Plan - Ground Floor Plan	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: October 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 01



Plan View

- Direction of measurement normal to the paper.
- Arrow shows direction of measurement.

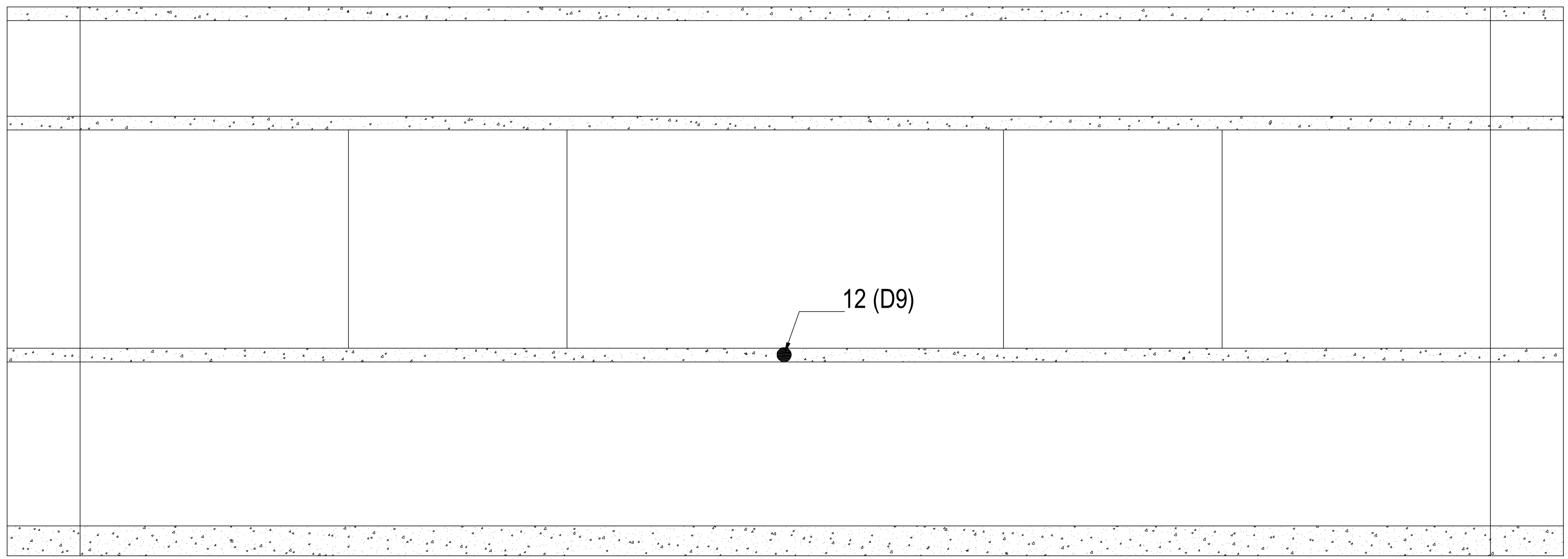
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Model) Type # 3	Instrumentation Plan - Eaves Level Plan	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: October 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 02



Front Wall Elevation
(Wall 1)

- ● Direction of measurement normal to the plane of paper.
- Arrow shows direction of measurement.

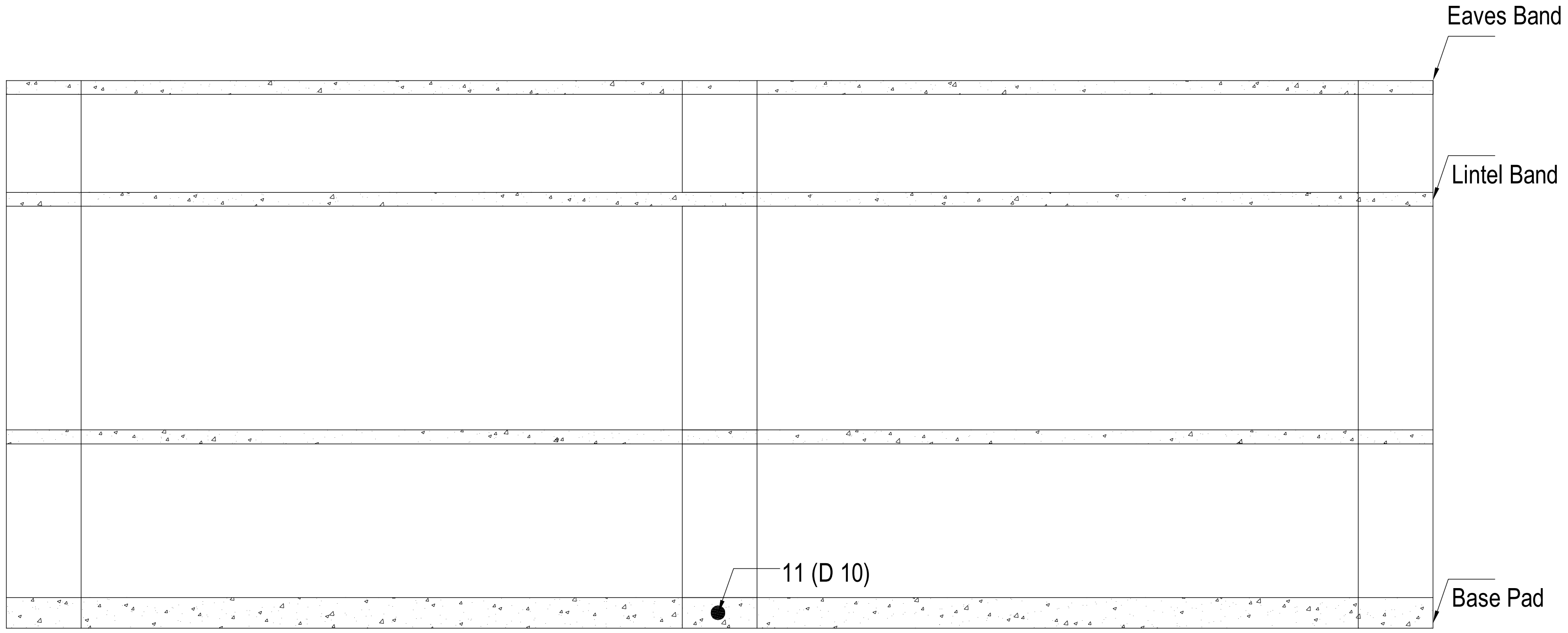
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Model) Type # 3	Instrumentation Plan - Waall 1	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: October 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 03



Back Wall Elevation
(Wall 2)

- Direction of measurement normal to the paper.
- Arrow shows direction of measurement.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Model) Type # 3	Instrumentation Plan - Wall 2	Dr. Qaisar Ali Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: October 2018 Scale: Read As Shown Dwg. No. 04

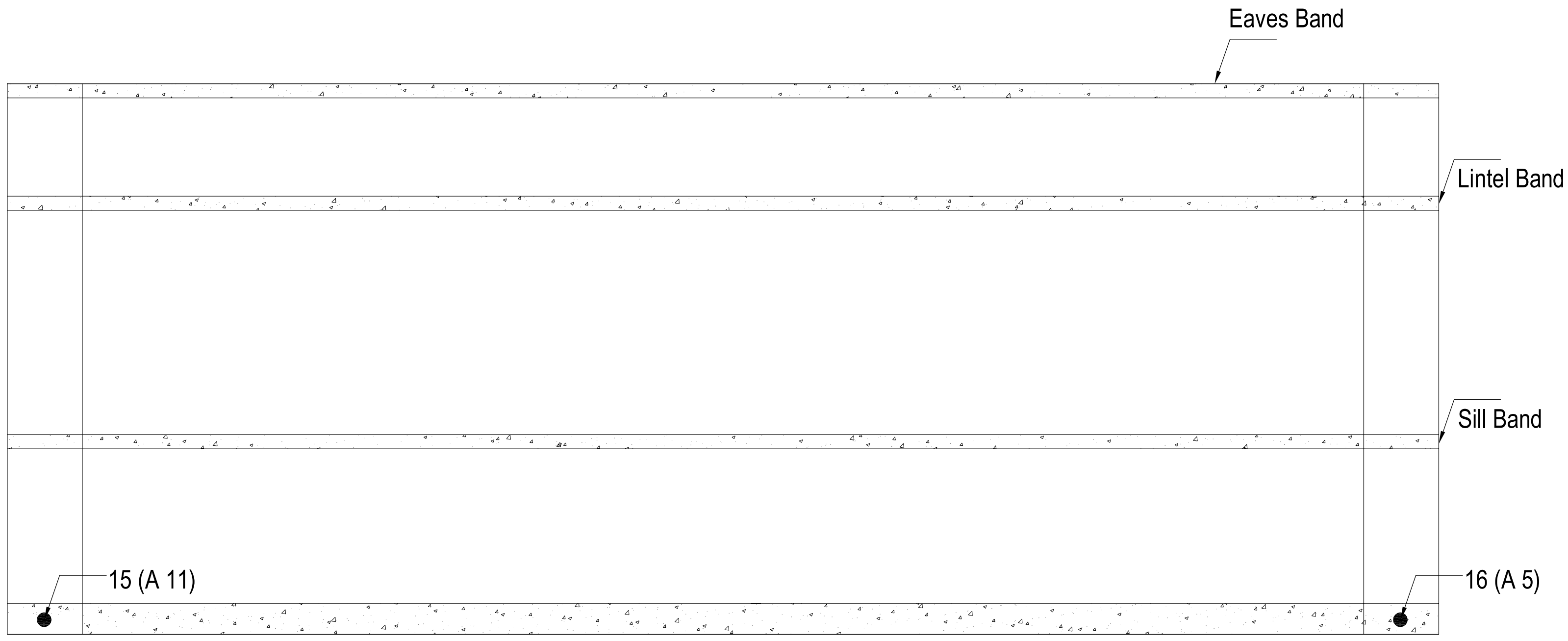


Side Elevation
(Wall 3)

● Direction of measurement normal to the paper.

↕ Arrow shows direction of measurement.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: October 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Model) Type # 3	Instrumentation Plan - Wall 3	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 05



Side Elevation
(Wall 4)

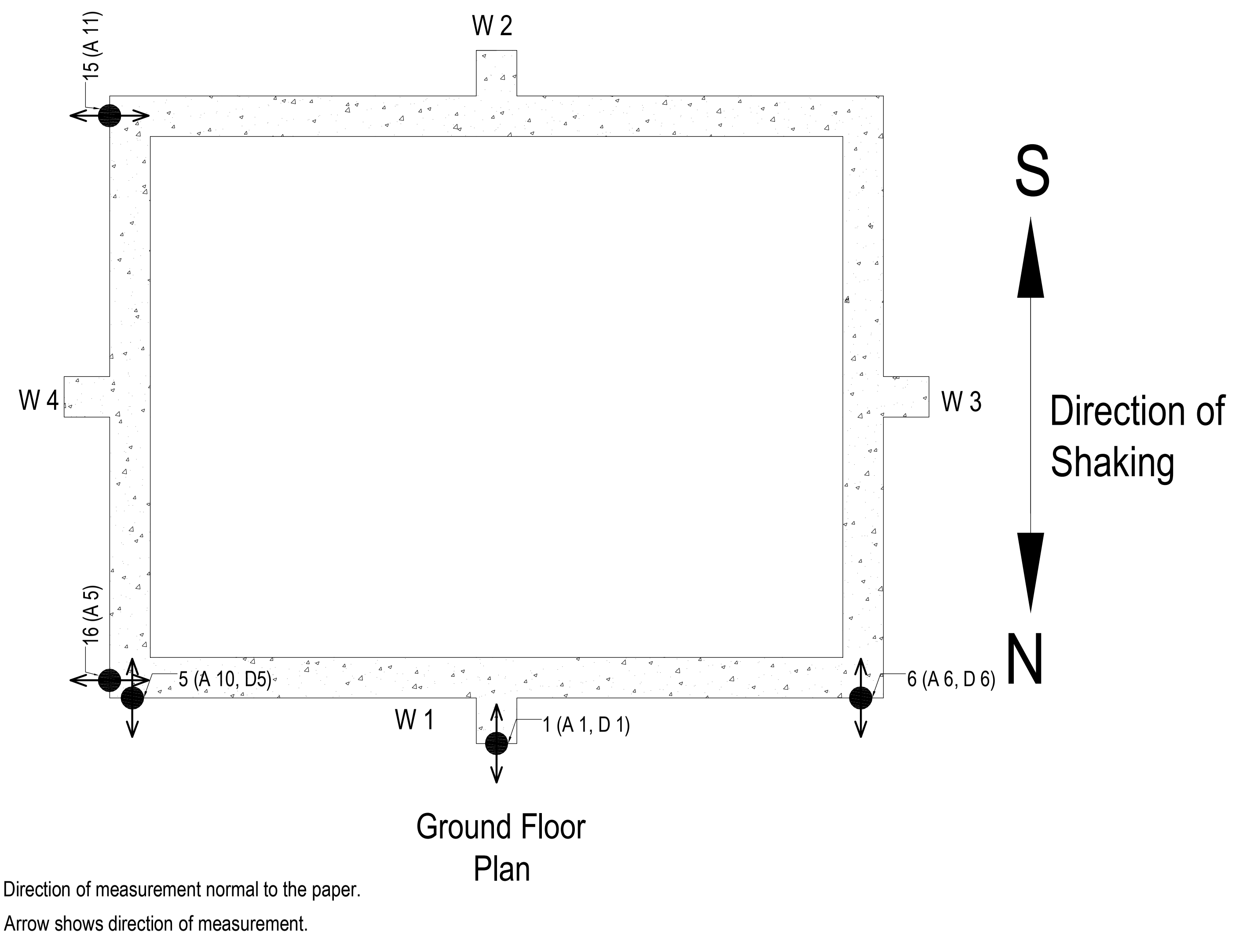
● Direction of measurement normal to the paper.

↕ Arrow shows direction of measurement.

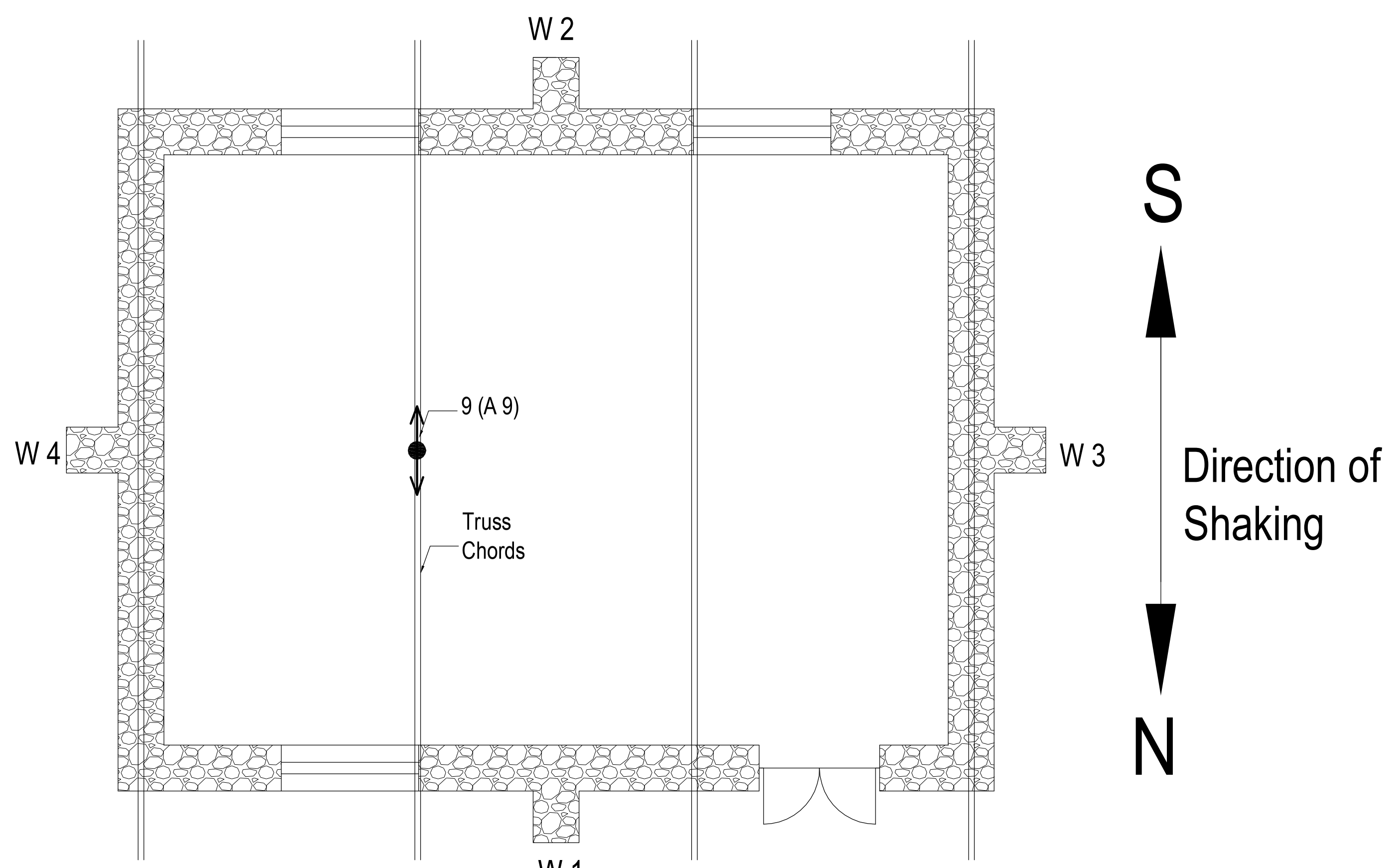
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: October 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (Two Third Scale Model) Type # 3	Instrumentation Plan - Wall 4	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 06

Appendix E4– Instrumentation Plan for 2/3rd Scale Model

(Type Design 4)



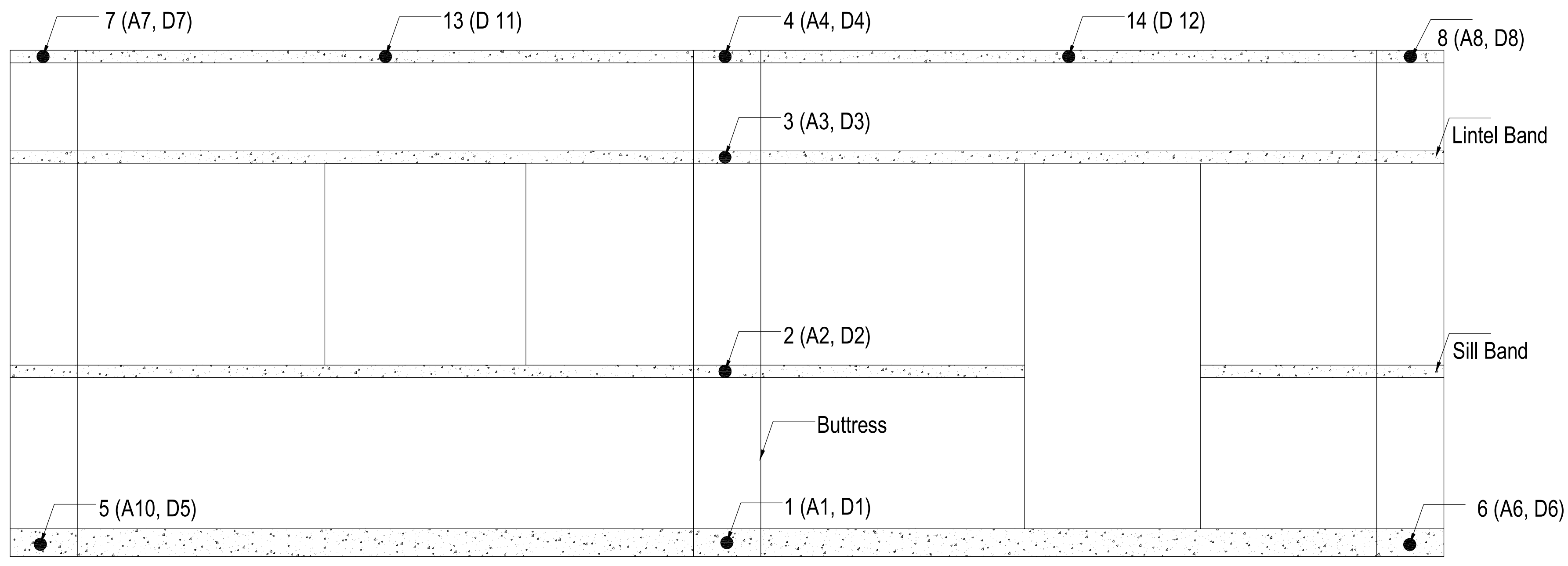
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands & Wire Containment (Two Third Scale Model) Type # 4	Instrumentation Plan - Ground Floor Plan	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 01



Plan View

- ● Direction of measurement normal to the paper.
- ↕ Arrow shows direction of measurement.

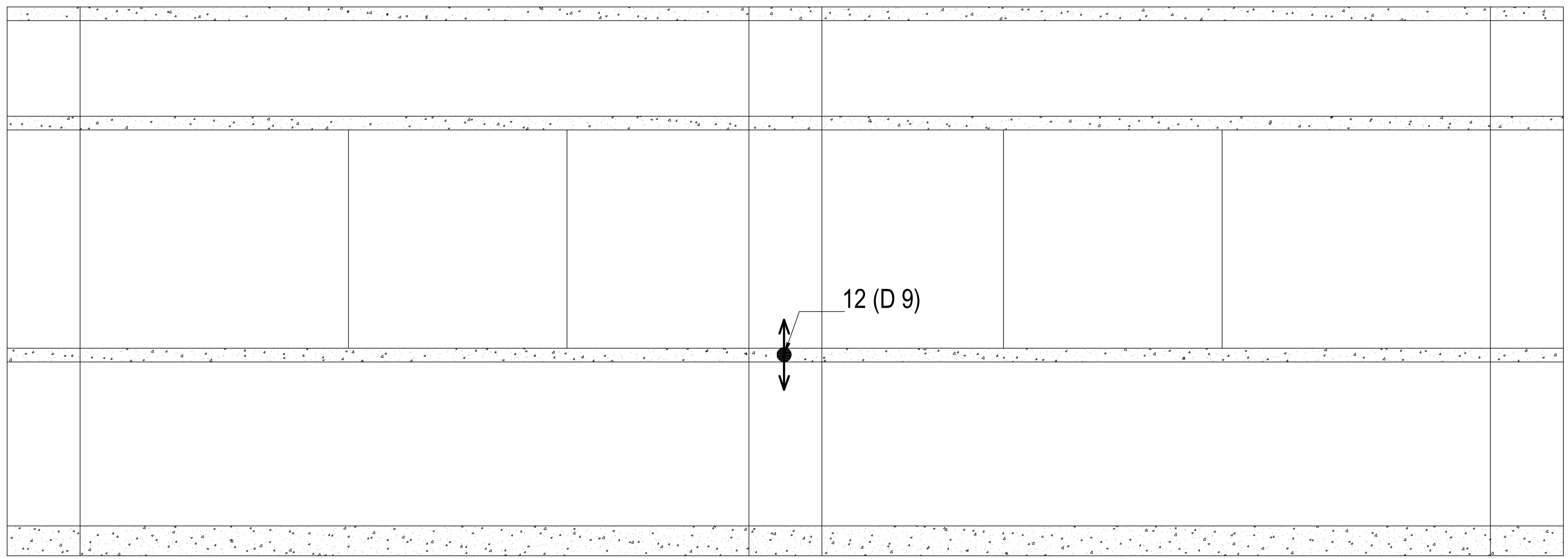
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands & Wire Containment (Two Third Scale Model) Type # 4	Instrumentation Plan - Eaves Level Plan	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 02



Front Wall Elevation
(Wall 1)

● Direction of measurement normal to the paper.
Arrow shows direction of measurement.

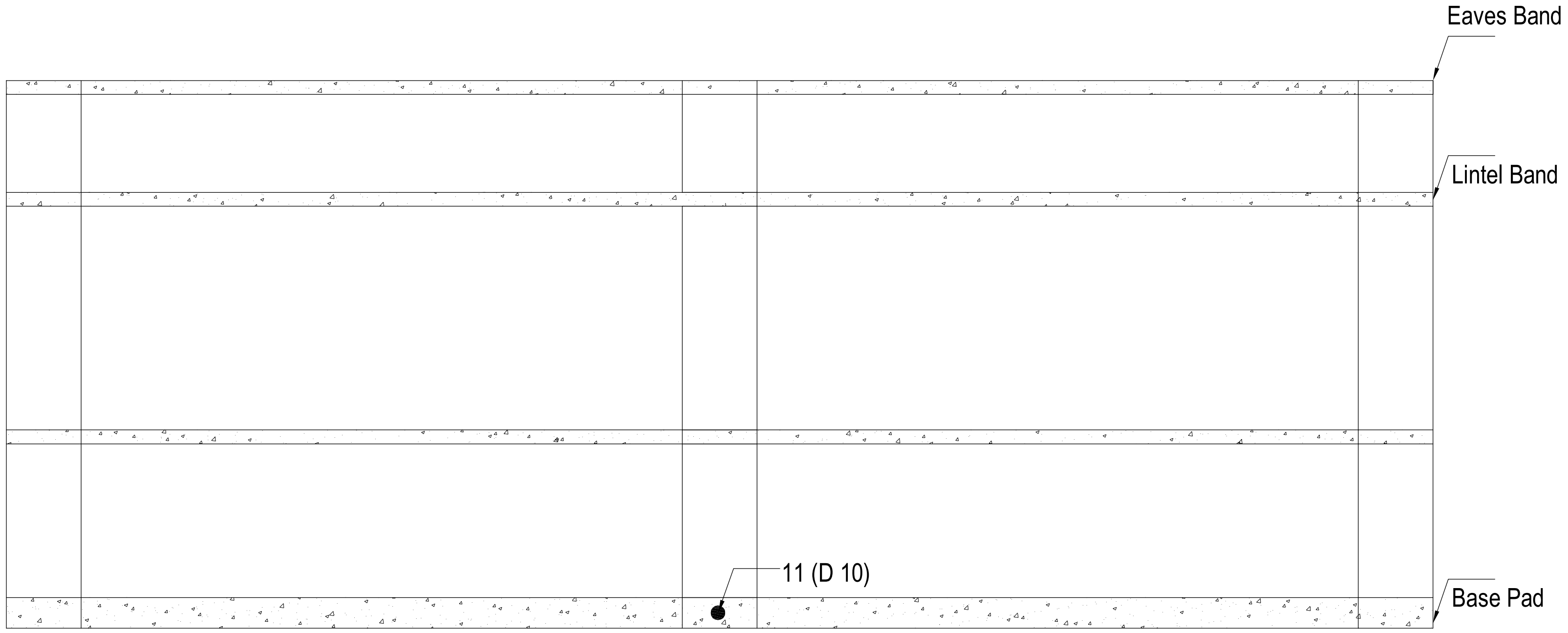
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands & Wire Containment (Two Third Scale Model) Type # 4	Instrumentation Plan - Waall 1	Dr. Qaisar Ali, Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 03



Back Wall Elevation
(Wall 2)

- Direction of measurement normal to the paper.
- Arrow shows direction of measurement.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands & Wire Containment (Two Third Scale Model) Type # 4	Instrumentation Plan - Wall 2	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018
					Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 04

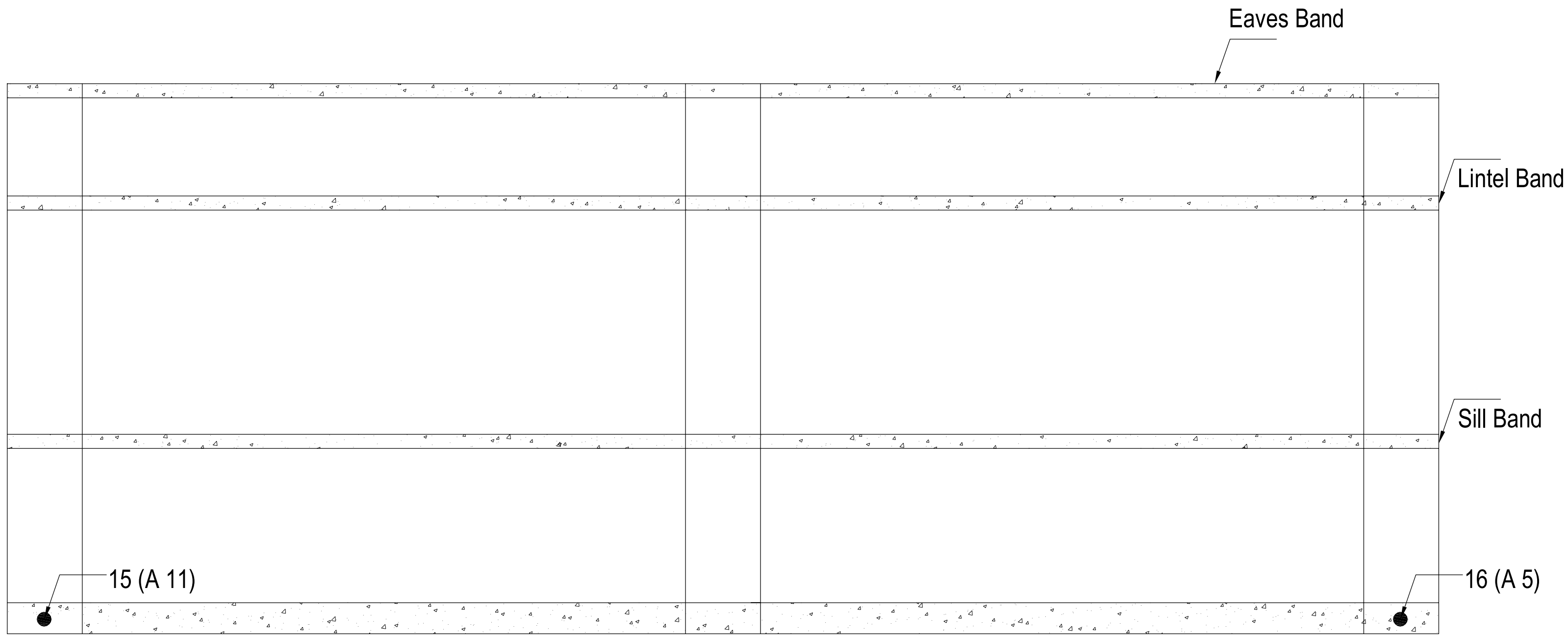


Side Elevation
(Wall 3)

● Direction of measurement normal to the paper.

↕ Arrow shows direction of measurement.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands & Wire Containment (Two Third Scale Model) Type # 4	Instrumentation Plan - Wall 3	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 05



Side Elevation
(Wall 4)

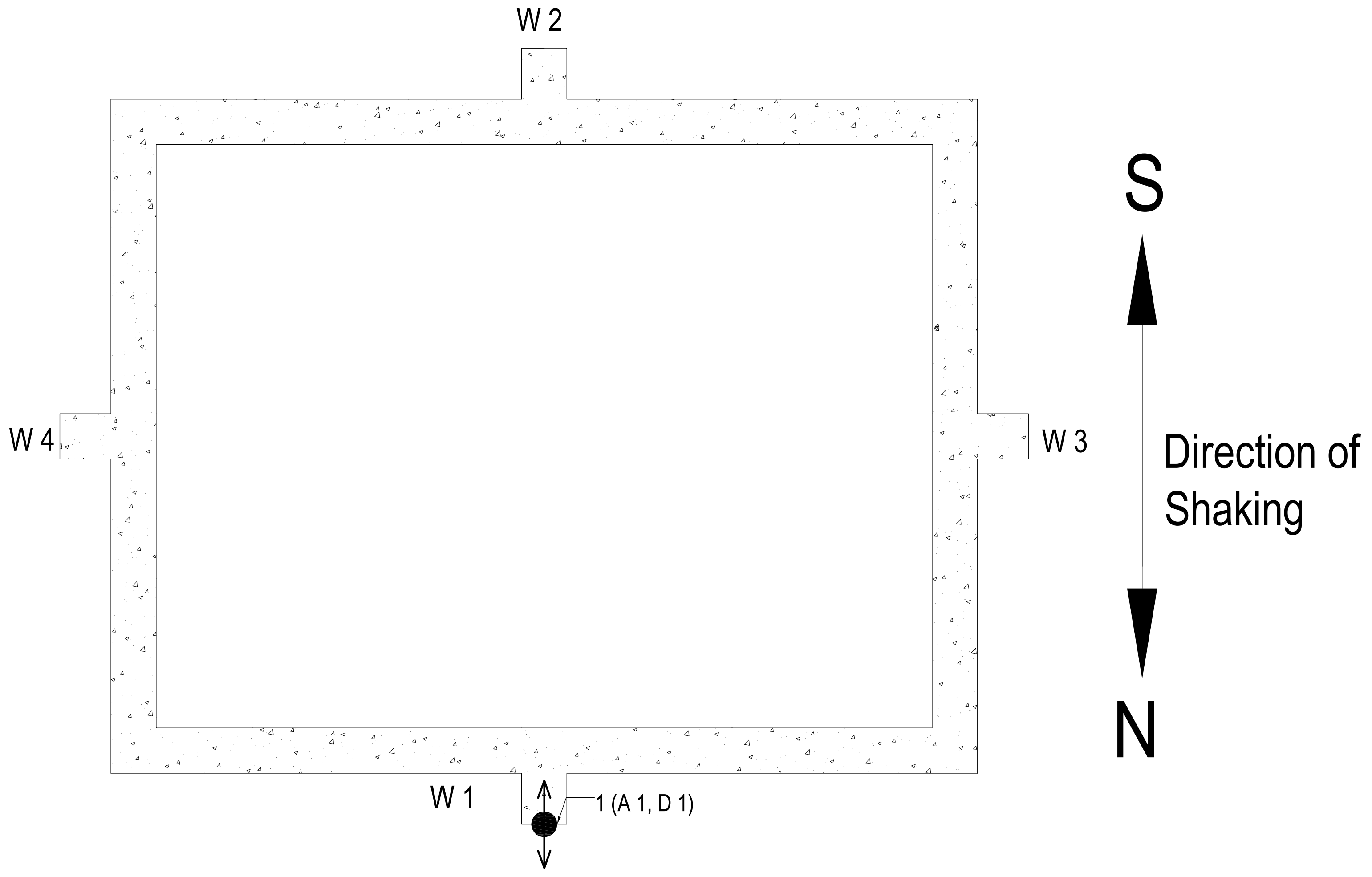
Direction of measurement normal to the paper.

Arrow shows direction of measurement.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands & Wire Containment (Two Third Scale Model) Type # 4	Instrumentation Plan - Wall 4	Dr. Qaisar Ali, Dr. Naveed Ahmad	Date: September 2018
					Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 06

Appendix F1 – Instrumentation Plan for 1/3rd Scale Model

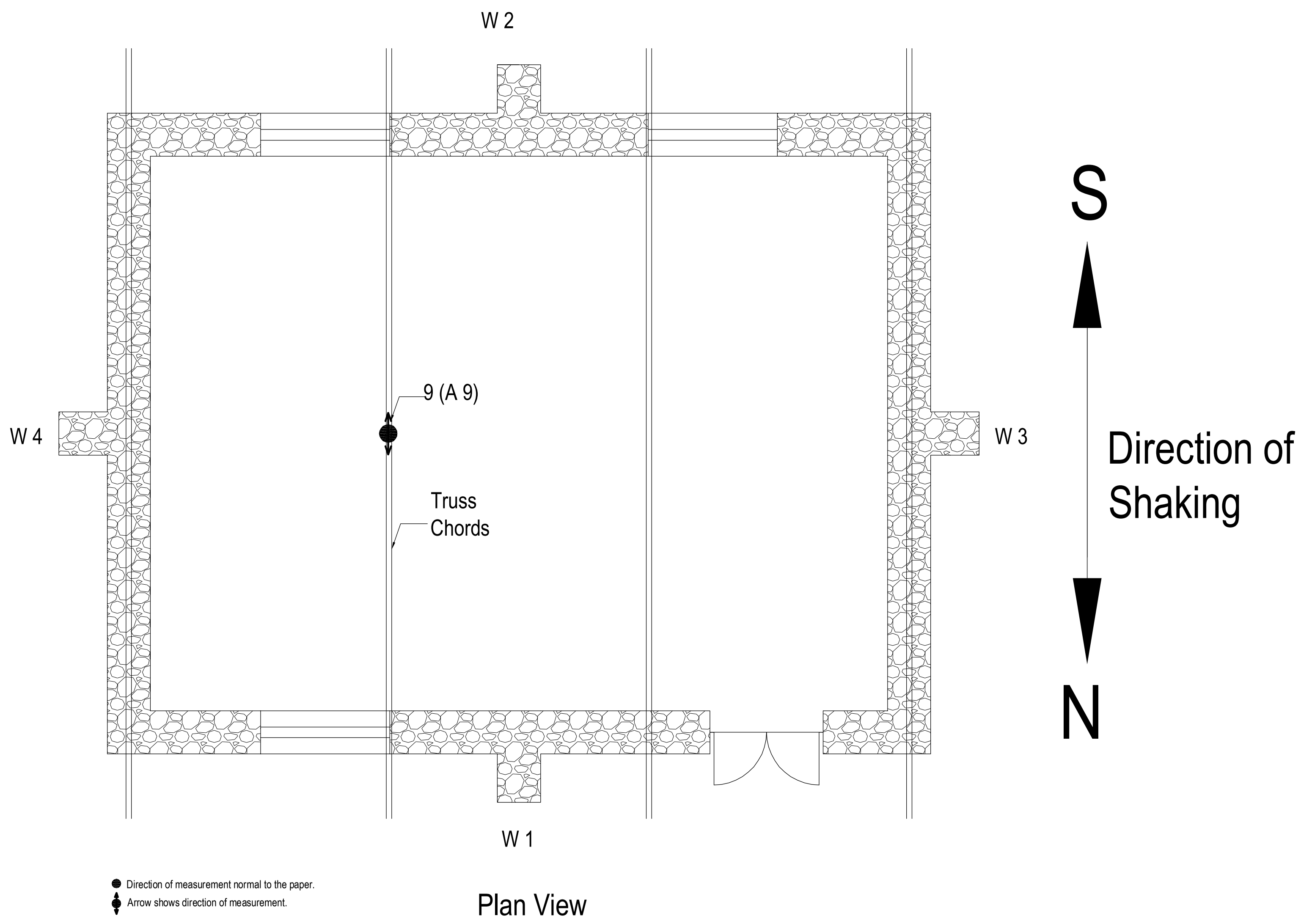
(Type Design 1)



Ground Floor
Plan View

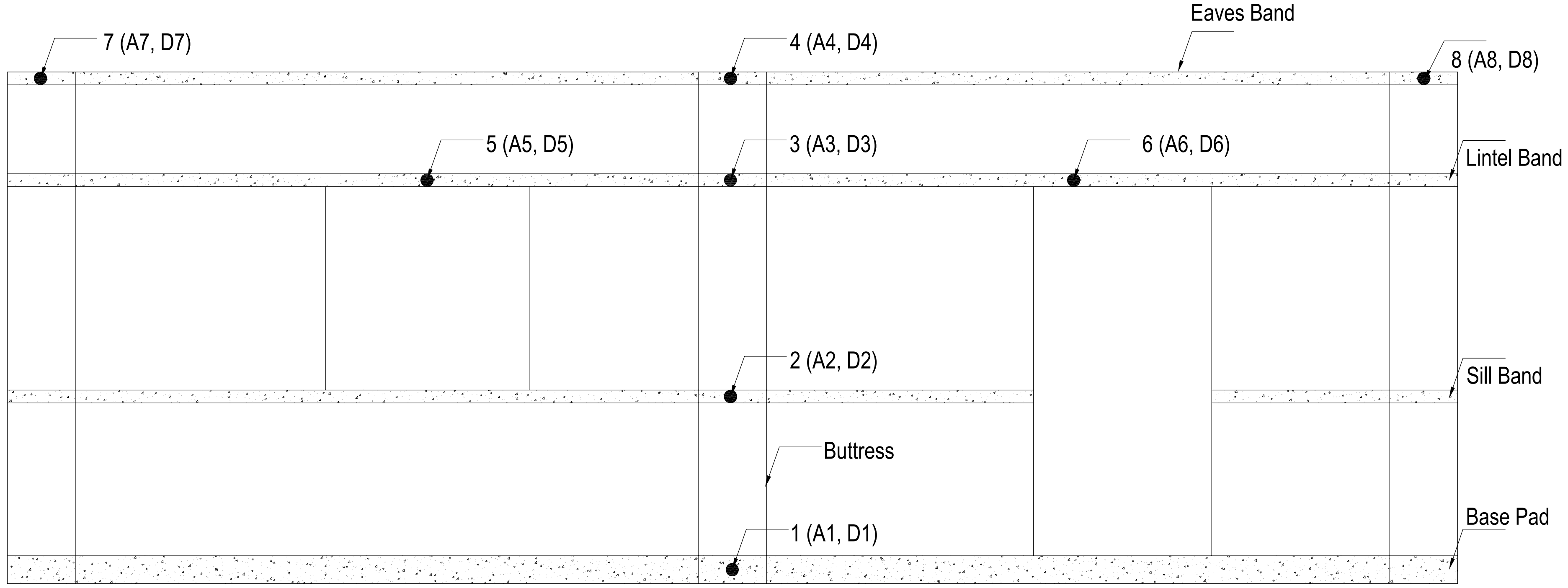
● Direction of measurement normal to the paper.
↕ Arrow shows direction of measurement.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry in Cement Stabilized Mud Mortar with RCC Bands (One Third Scale Model) Type # 1	Instrumentation Plan - Ground Floor Plan	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 01



Plan View

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry in Cement Stabilized Mud Mortar with RCC Bands (One Third Scale Model) Type # 1	Instrumentation Plan - Eaves Level Plan	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 02

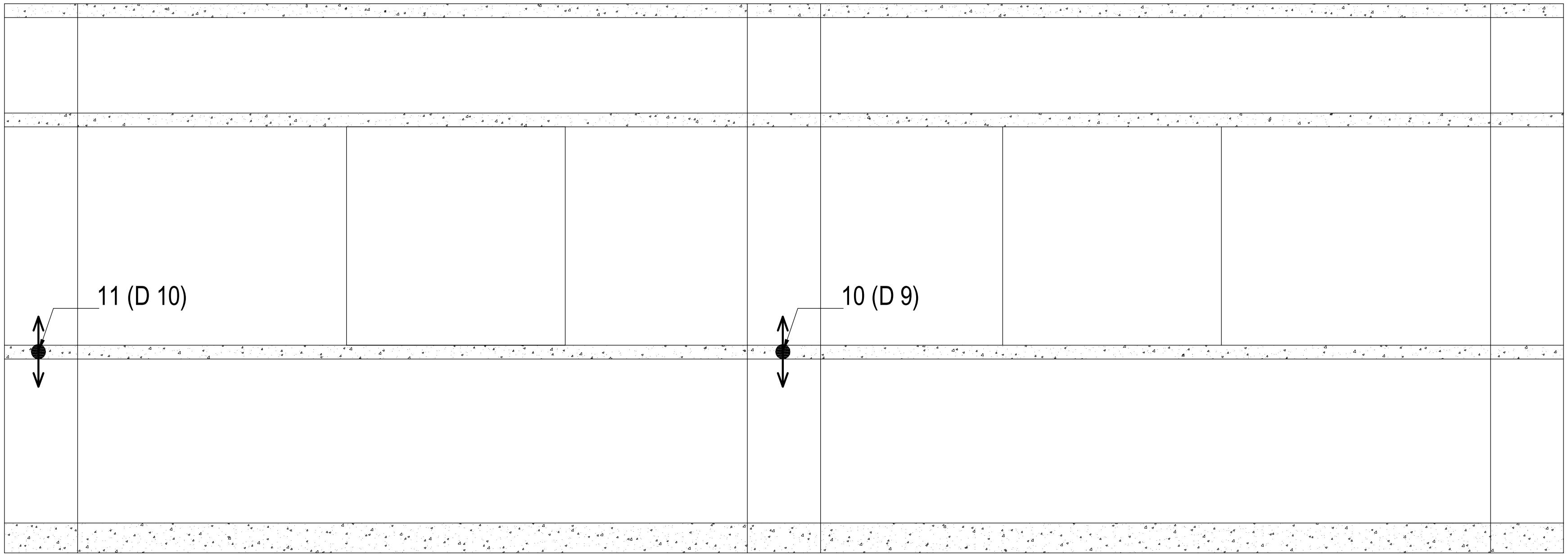


● Direction of measurement normal to the paper.

Arrow shows direction of measurement.

Front Wall Elevation (Wall 1)

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry in Cement Stabilized Mud Mortar with RCC Bands (One Third Scale Model) Type # 1	Instrumentation Plan - Wall 1	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 03



Direction of measurement normal to the paper.

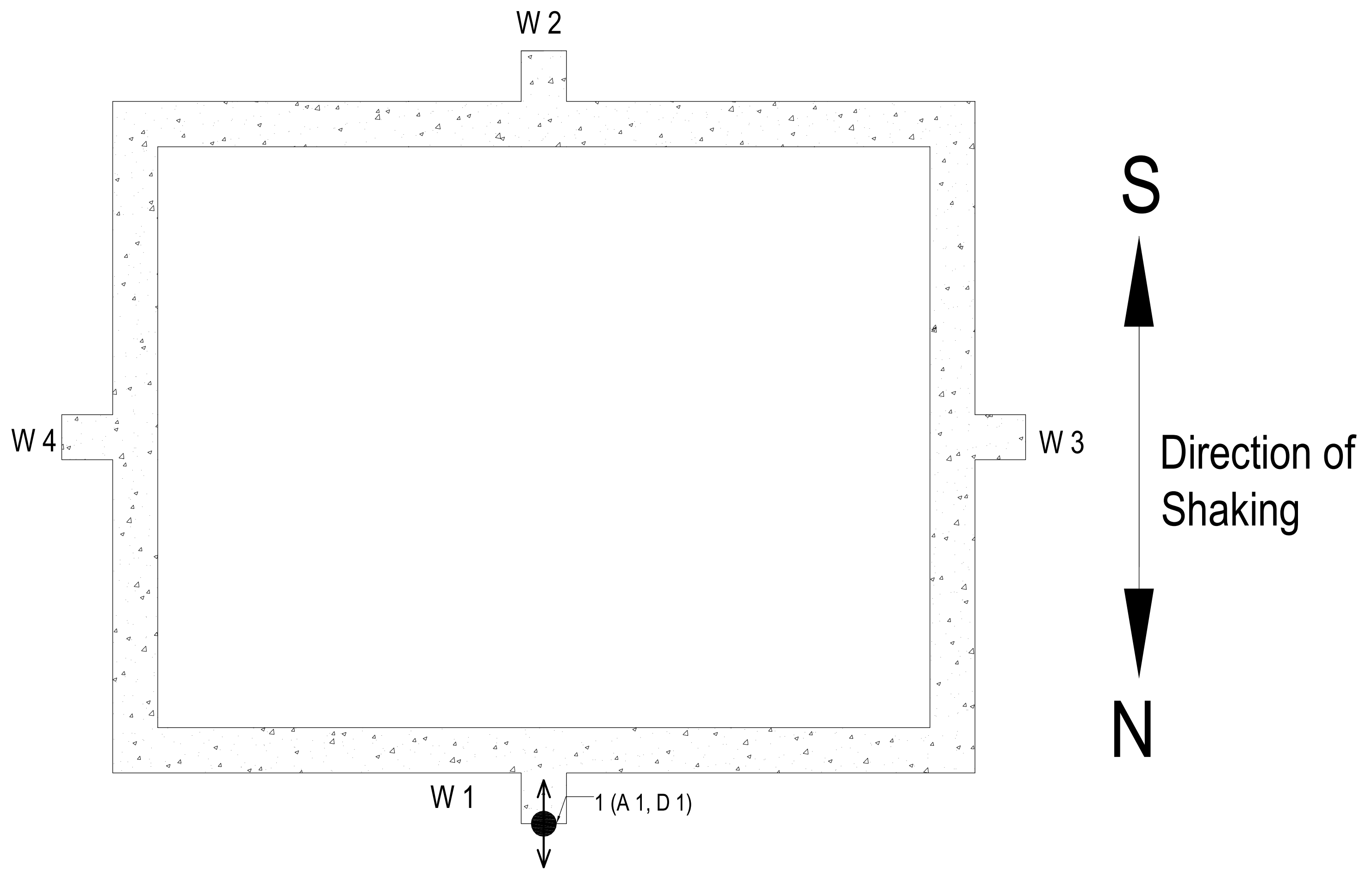
Arrow shows direction of measurement.

Back Wall Elevation
(Wall 2)

Consultant Name: University of Engineering and Technology Peshawar.	Client Name: Asian Development Bank	Design Type: Semidressed Stone Masonry in Cement Stabilized Mud Mortar with RCC Bands (One Third Scale Model) Type # 1	TITLE: Instrumentation Plan - Wall 2	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad; Drafted by: Engr. Attaur Rahman	Date: September 2018; Scale: Read As Shown; Dwg. No. 04

Appendix F2 – Instrumentation Plan for 1/3rd Scale Model

(Type Design 2)

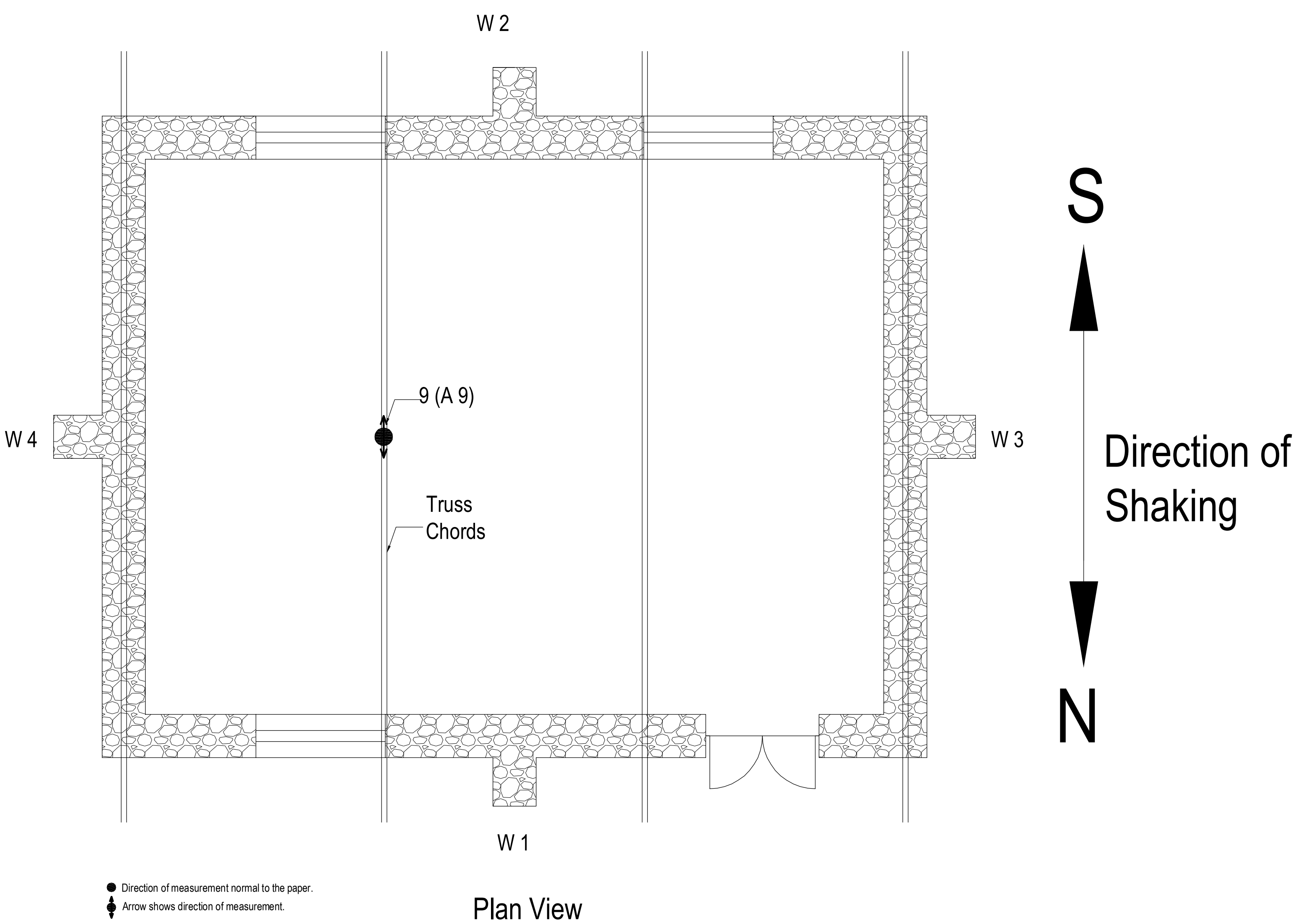


Ground Floor
Plan View

● Direction of measurement normal to the paper.

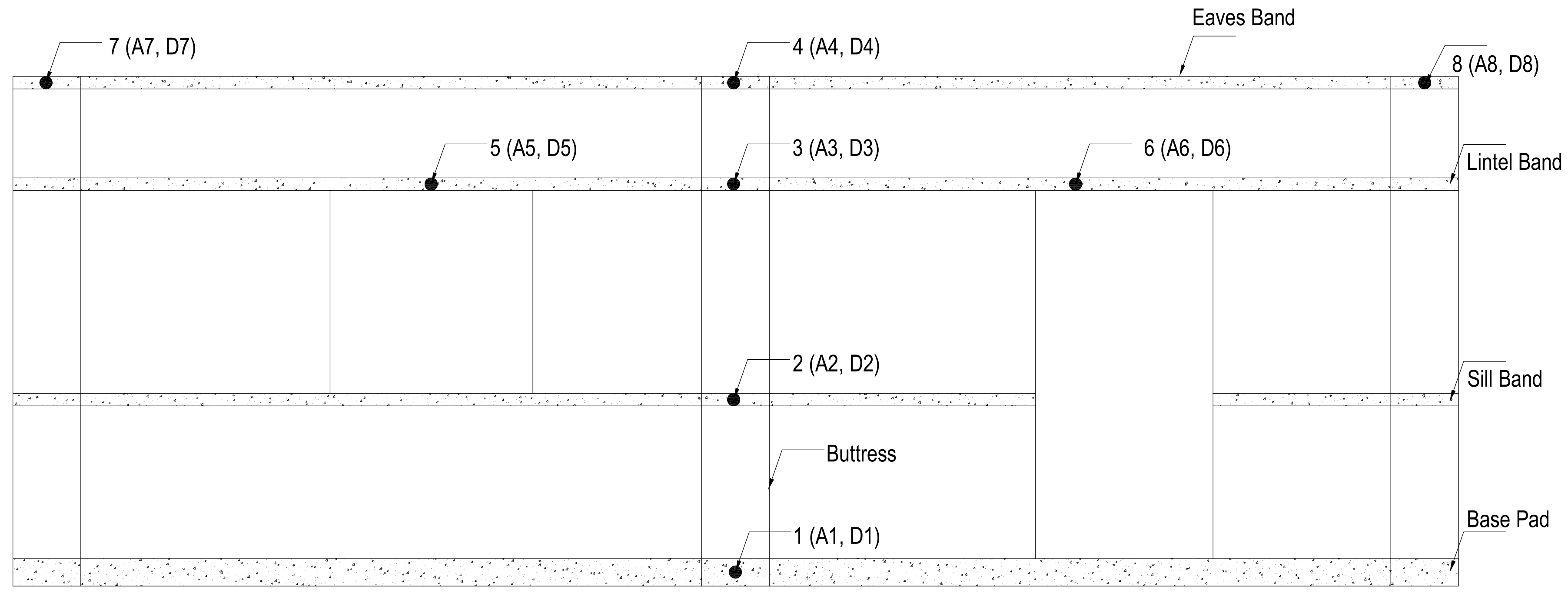
Arrow shows direction of measurement.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabian Mesh/ Geogrid Bands & Wire Containment (Type 2 One Third Scale Model) [Transverse Direction]	Instrumentation Plan Ground Floor Plan View	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 01 T



Plan View

Consultant Name: University of Engineering and Technology Peshawar.	Client Name: Asian Development Bank	Design Type: Semidressed Stone Masonry with Gabian Mesh/ Geogrid Bands & Wire Containment (Type 2 One Third Scale Model) [Transverse Direction]	TITLE: Instrumentation Plan Eaves Level Plan	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad; Drafted by: Engr. Attaur Rahman	Date: September 2018; Scale: Read As Shown; Dwg. No. 02 T

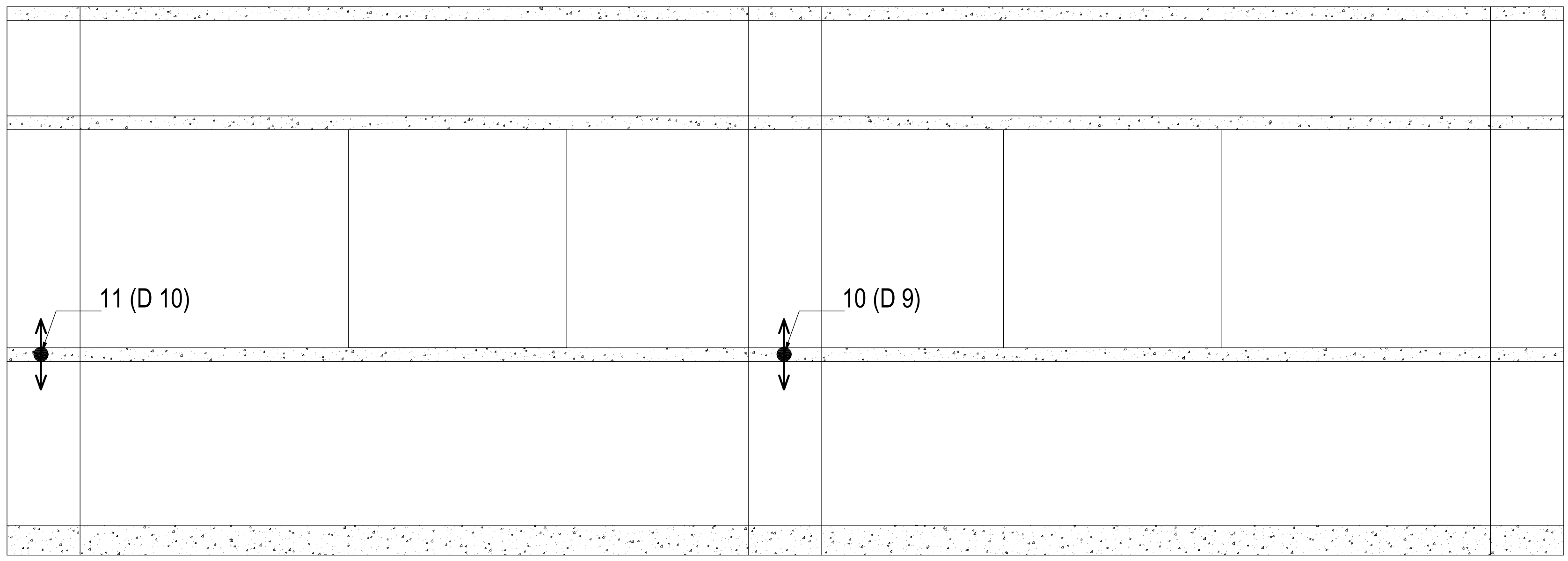


Direction of measurement normal to the paper.

Arrow shows direction of measurement.

Front Wall Elevation (Wall 1)

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabian Mesh/ Geogrid Bands & Wire Containment (Type 2 One Third Scale Model) [Transverse Direction]	Instrumentation Plan Wall 1	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 03 T

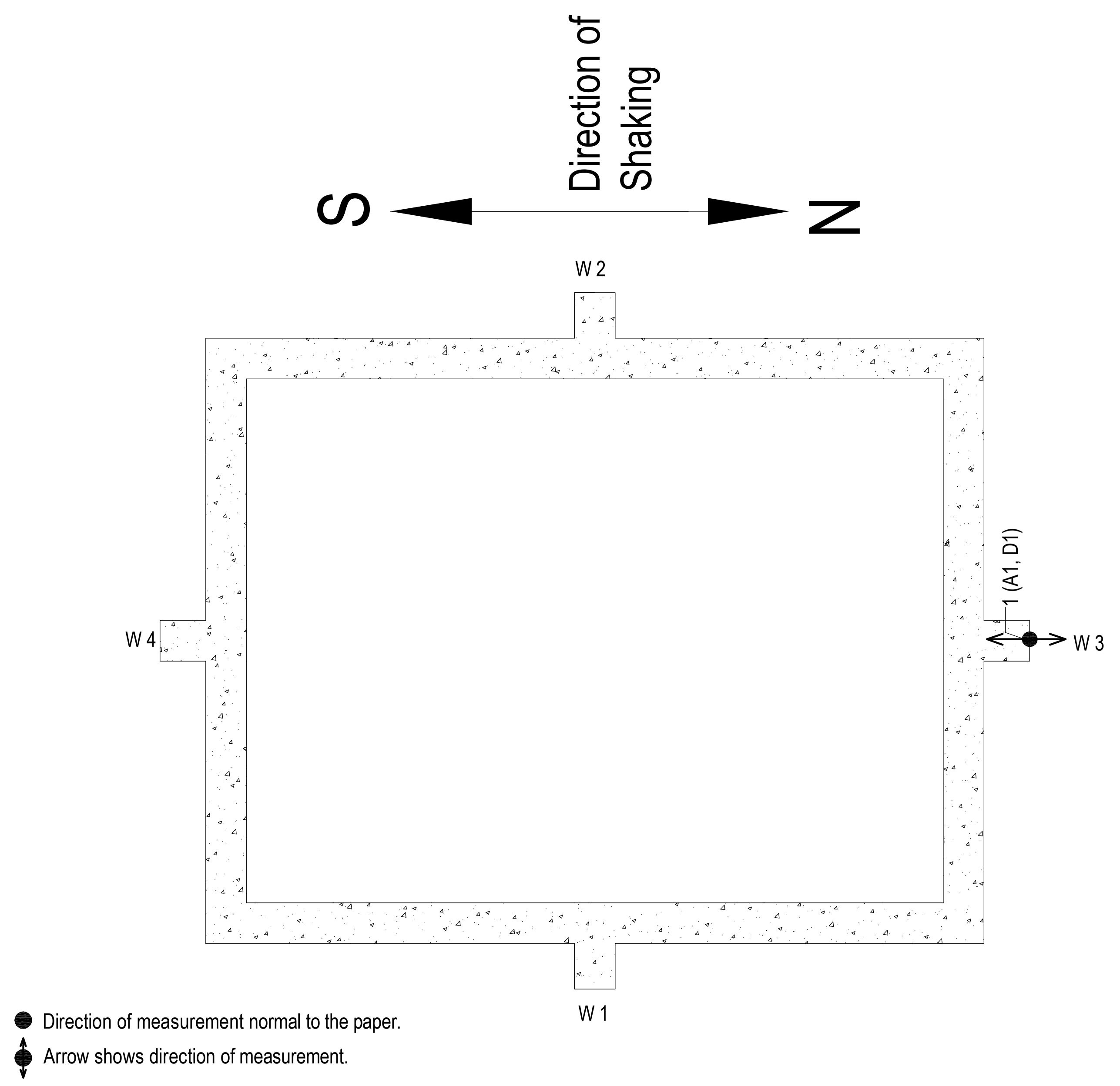


Direction of measurement normal to the paper.

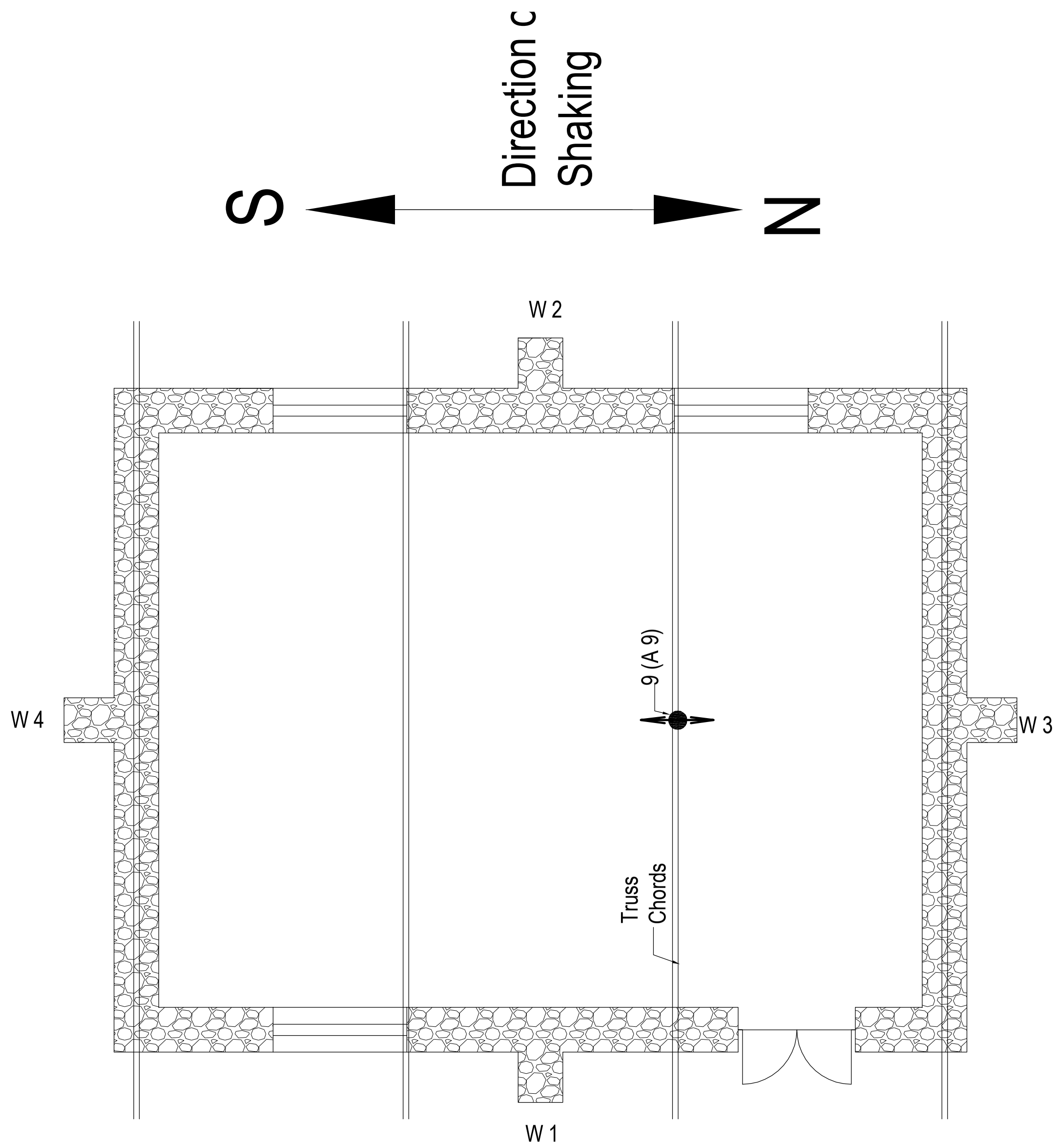
Arrow shows direction of measurement.

Back Wall Elevation
(Wall 2)

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabian Mesh/ Geogrid Bands & Wire Containment (Type 2 One Third Scale Model) [Transverse Direction]	Instrumentation Plan Wall 2	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 04 T



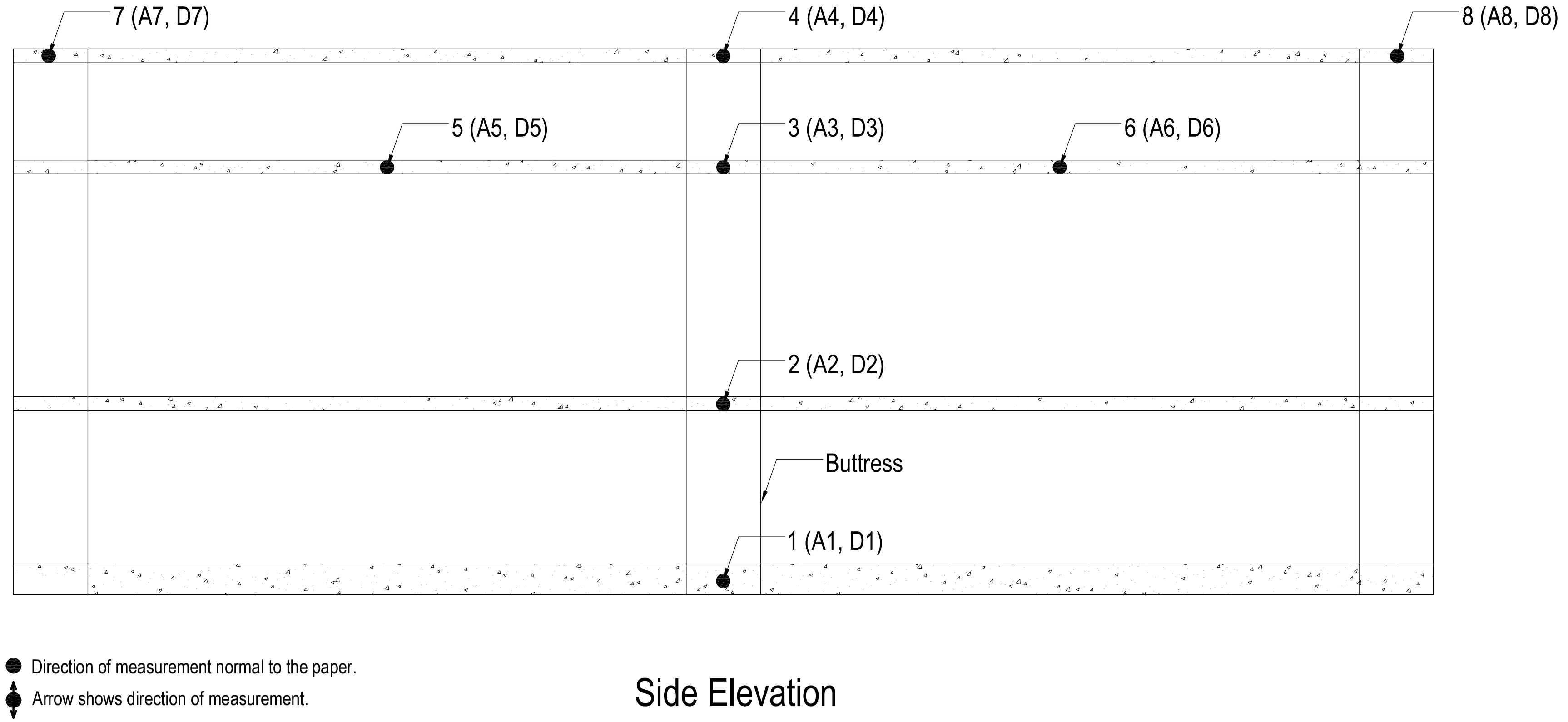
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabian Mesh/ Geogrid Bands & Wire Containment (Type 2 One Third Scale Model) [Longitudinal Direction]	Instrumentation Plan Ground Floor Plan	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 01 L



Direction of measurement normal to the paper.

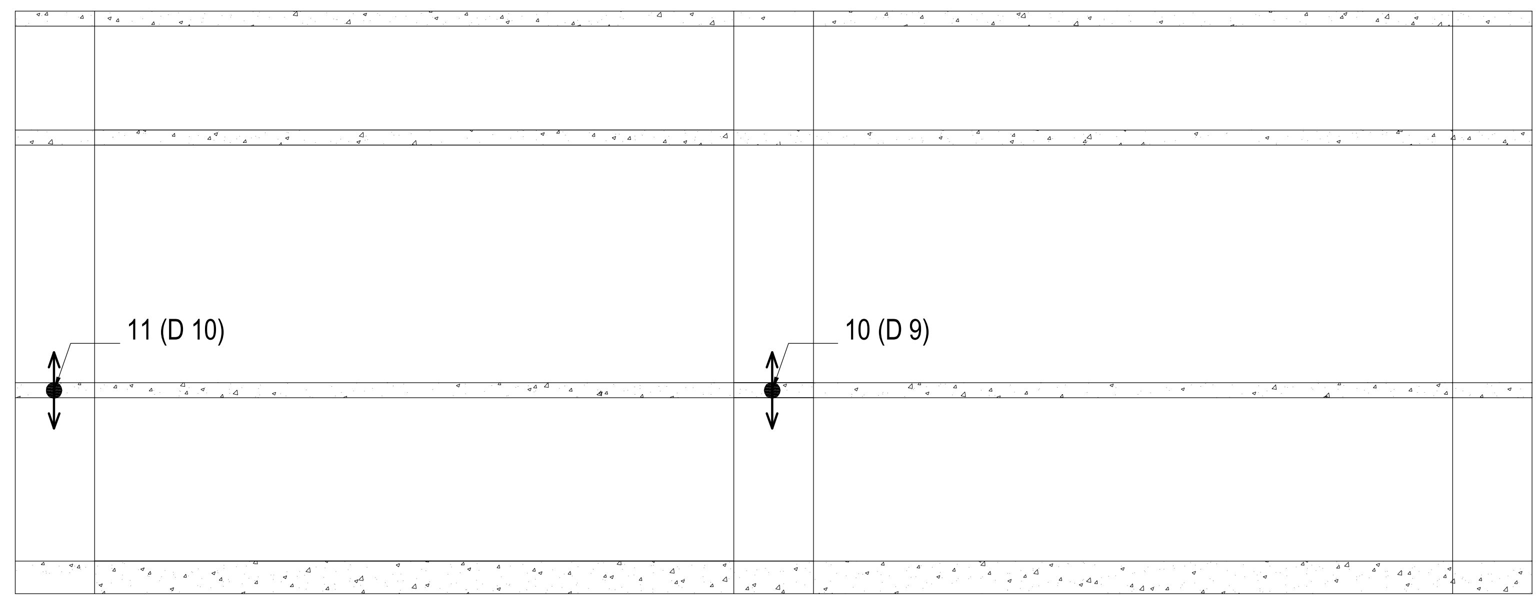
Arrow shows direction of measurement.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabian Mesh/ Geogrid Bands & Wire Containment (Type 2 One Third Scale Model) [Longitudinal Direction]	Instrumentation Plan Eaves Level Plan	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 02 L



Side Elevation
(Wall 3)

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabian Mesh/ Geogrid Bands & Wire Containment (Type 2 One Third Scale Model) [Longitudinal Direction]	Instrumentation Plan Wall 3	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 03 L



Direction of measurement normal to the paper.

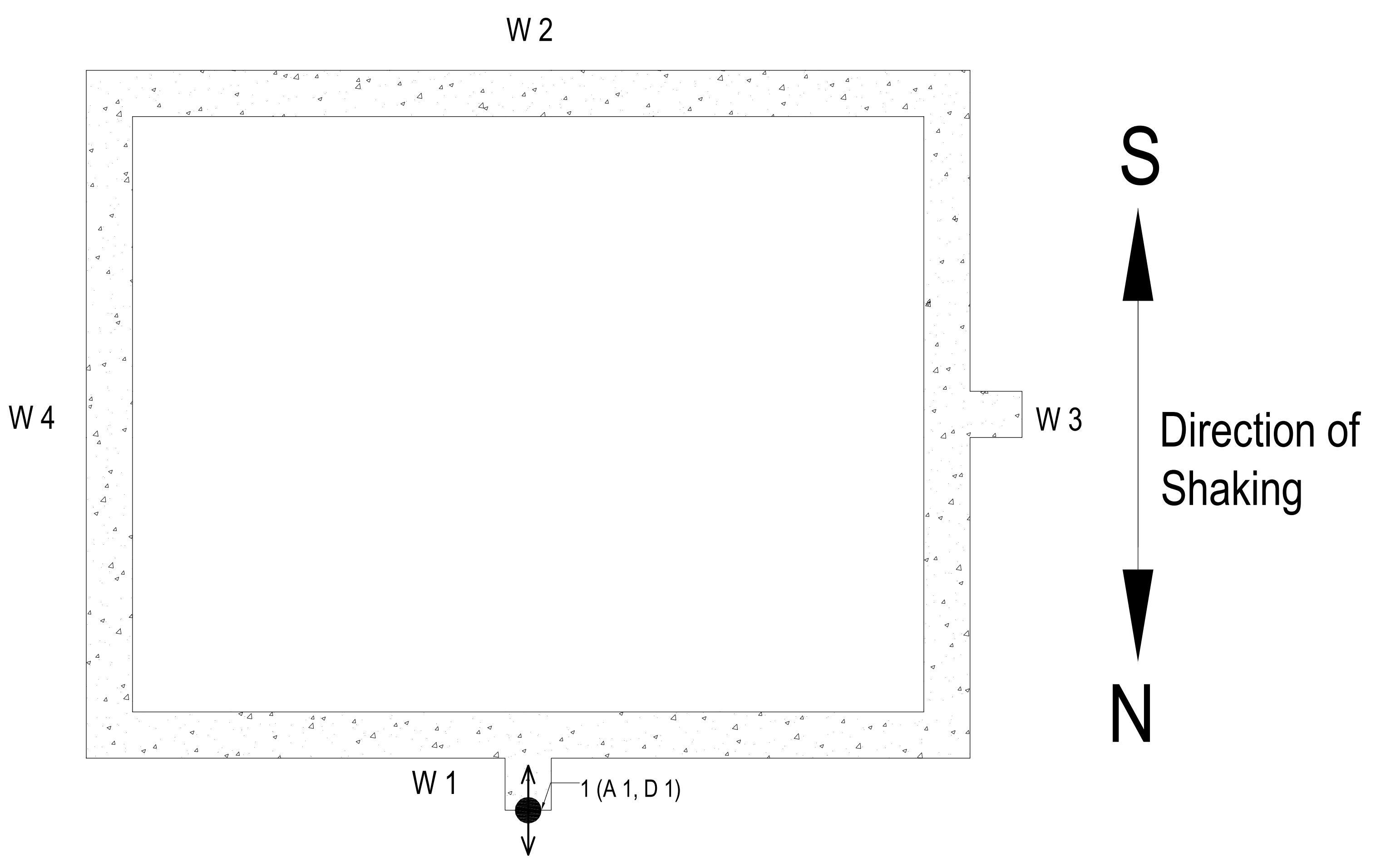
Arrow shows direction of measurement.

Side Elevation
(Wall 4)

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Gabian Mesh/ Geogrid Bands & Wire Containment (Type 2 One Third Scale Model) [Longitudinal Direction]	Instrumentation Plan Wall 4	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: September 2018
				Drafted by: Engr. Attaur Rahman	Scale: Read As Shown Dwg. No. 04 L

Appendix F3 – Instrumentation Plan for 1/3rd Scale Model

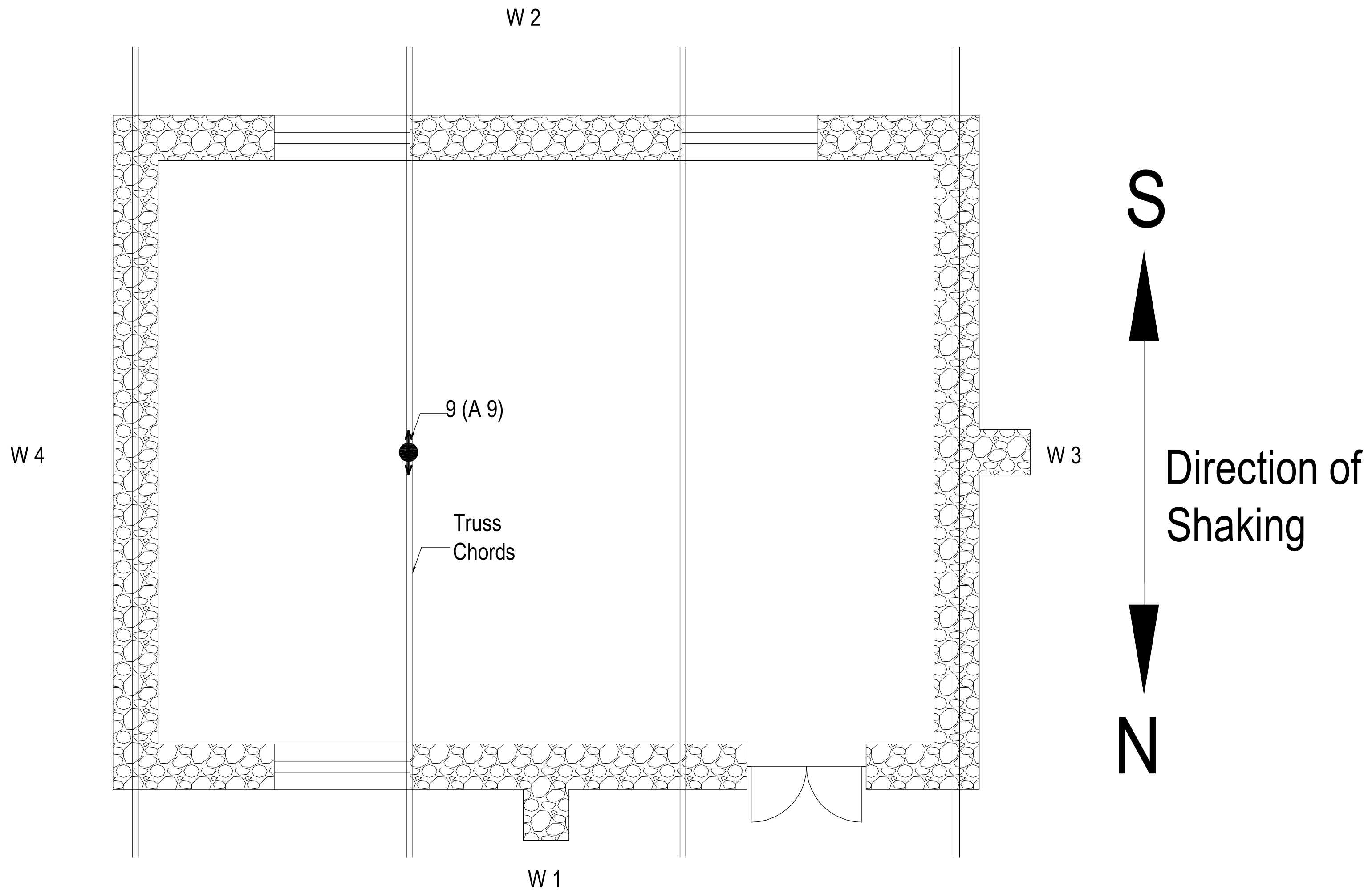
(Type Design 3)



Ground Floor Plan View

- Direction of measurement normal to the paper.
- Arrow shows direction of measurement.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Scale Model) Type # 3	Instrumentation Plan - Ground Floor Plan (Transverse Direction)	Dr. Qaisar Ali Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: October 2018 Scale: Read As Shown Dwg. No. 01 T

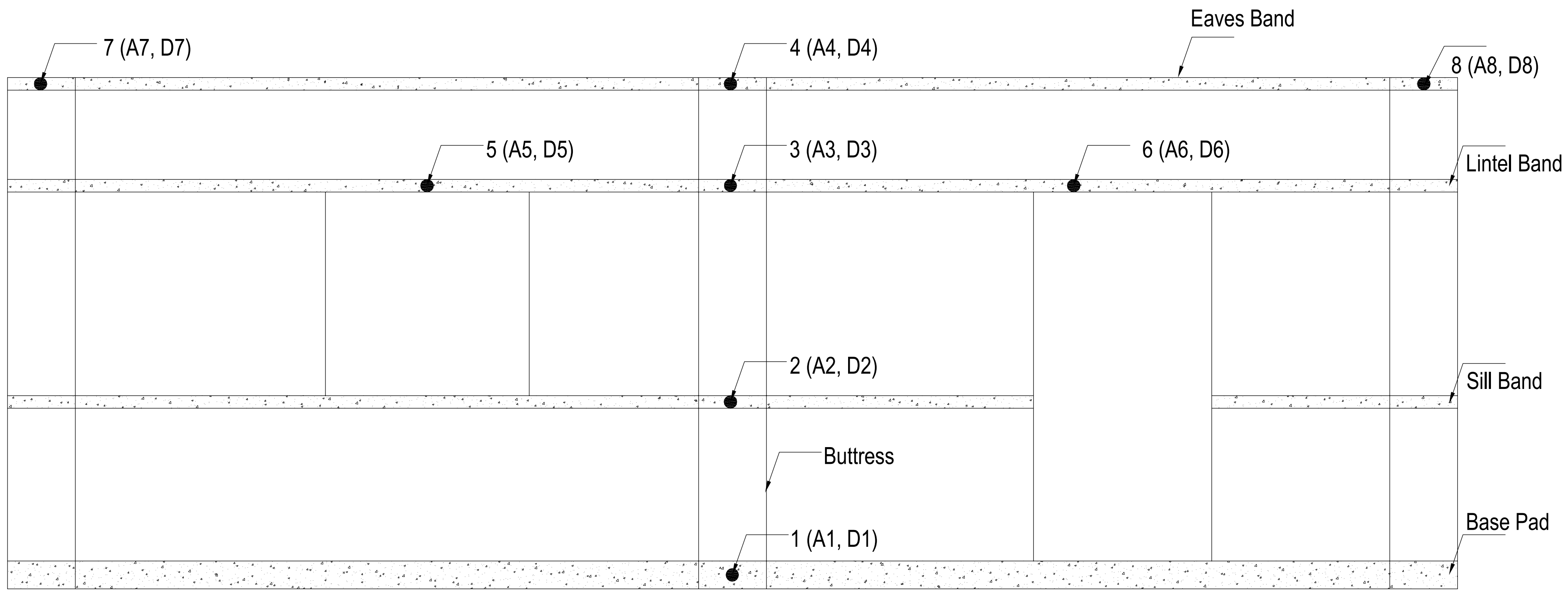


Direction of measurement normal to the paper.

Arrow shows direction of measurement.

Plan View

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Scale Model) Type # 3	Instrumentation Plan - Eaves Level Plan (Transverse Direction)	Dr. Qaisar Ali Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: October 2018 Scale: Read As Shown Dwg. No. 02 T

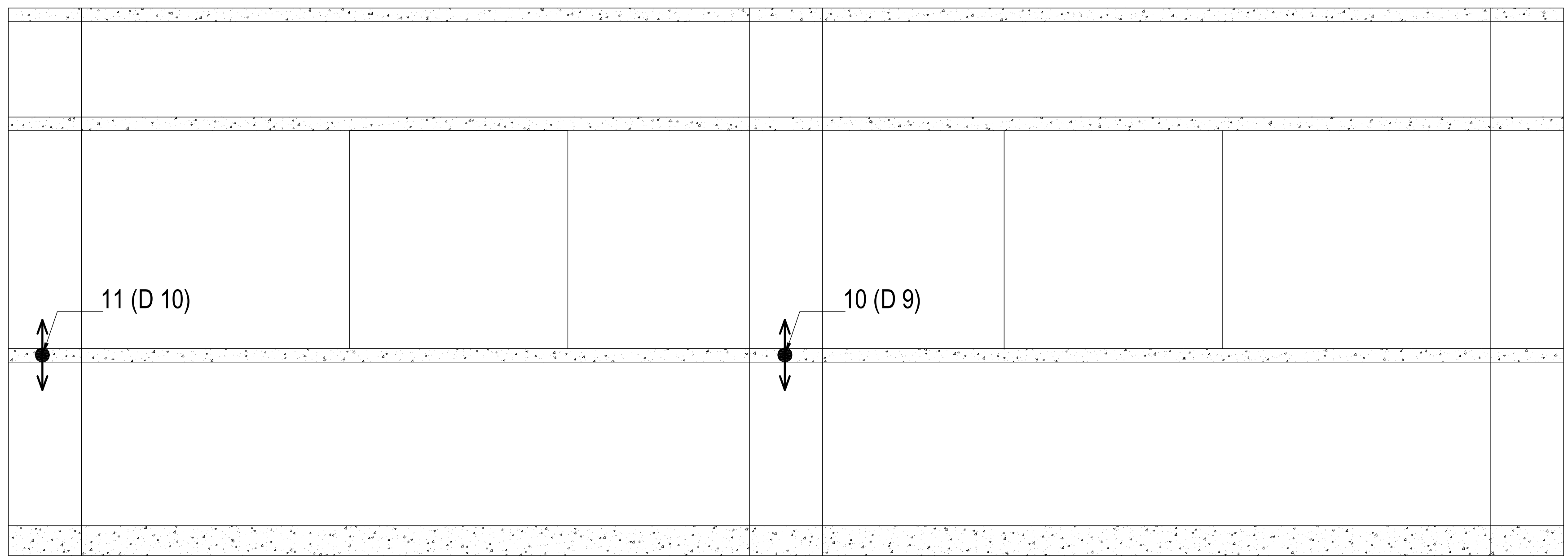


● Direction of measurement normal to the paper.

↕ Arrow shows direction of measurement.

Front Wall Elevation
(Wall 1)

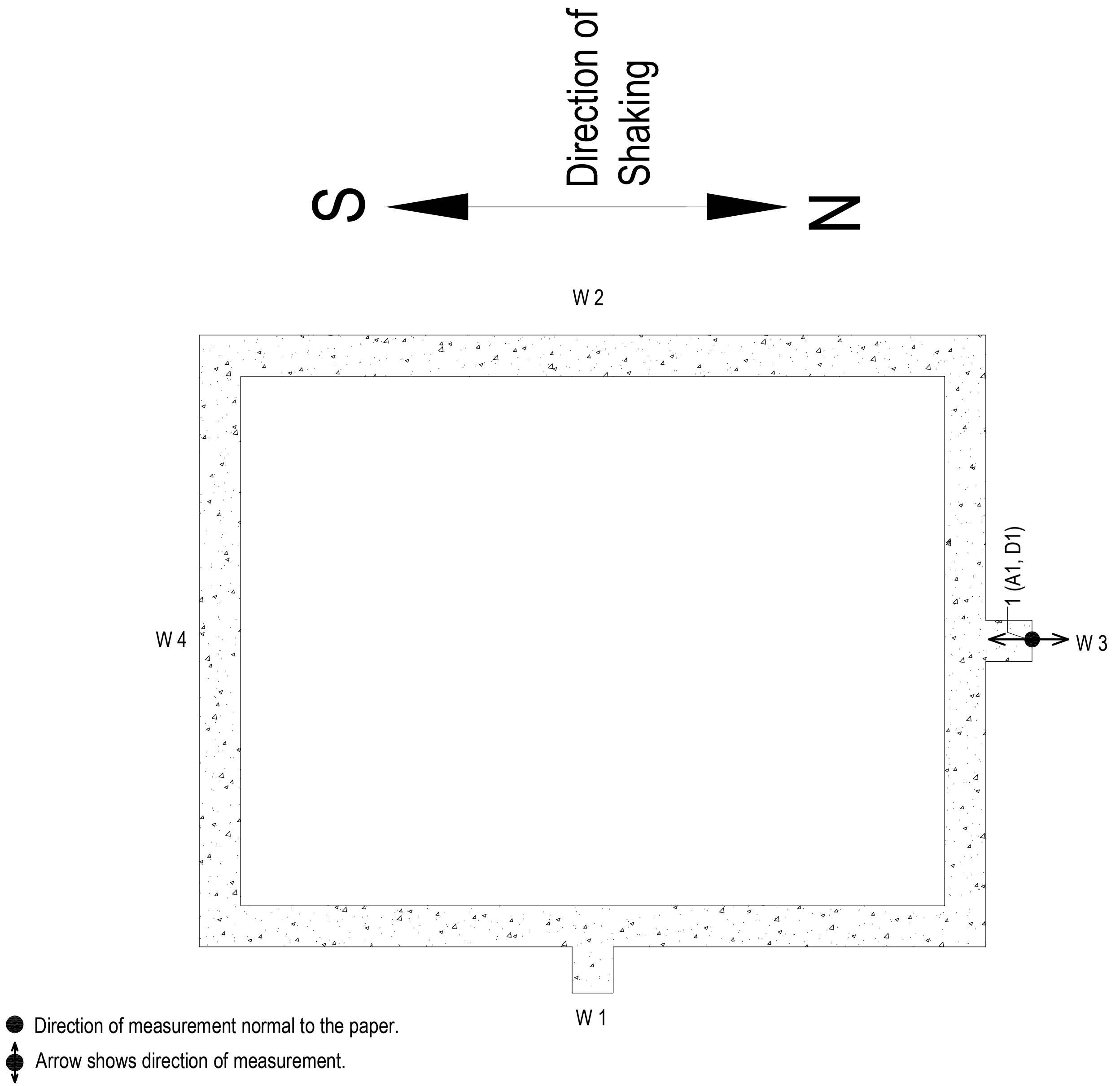
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: October 2018
University of Engineering and Technology Peshawar.	ADB Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Scale Model) Type # 3	Instrumentation Plan - Wall 1 (Transverse Direction)	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 03 T



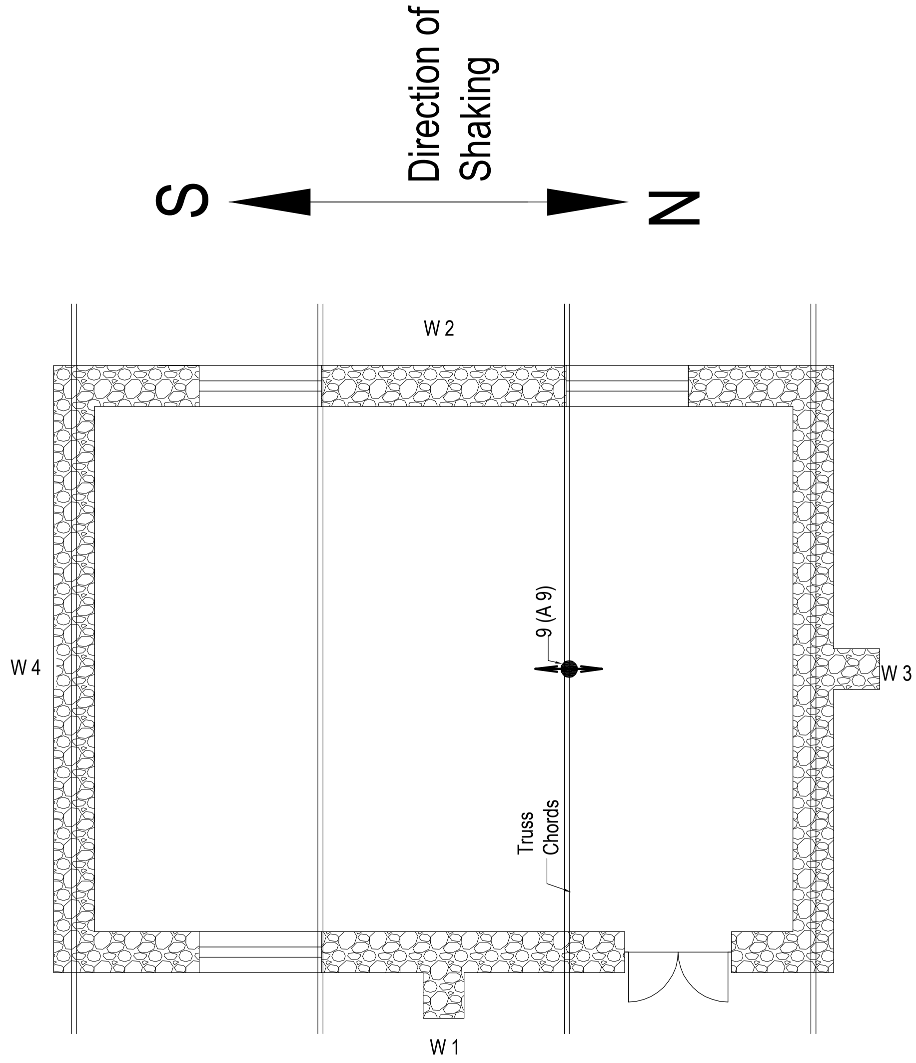
Direction of measurement normal to the paper.
Arrow shows direction of measurement.

Back Wall Elevation (Wall 2)

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Scale Model) Type # 3	Instrumentation Plan - Wall 2 (Transverse Direction)	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: October 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 04 T



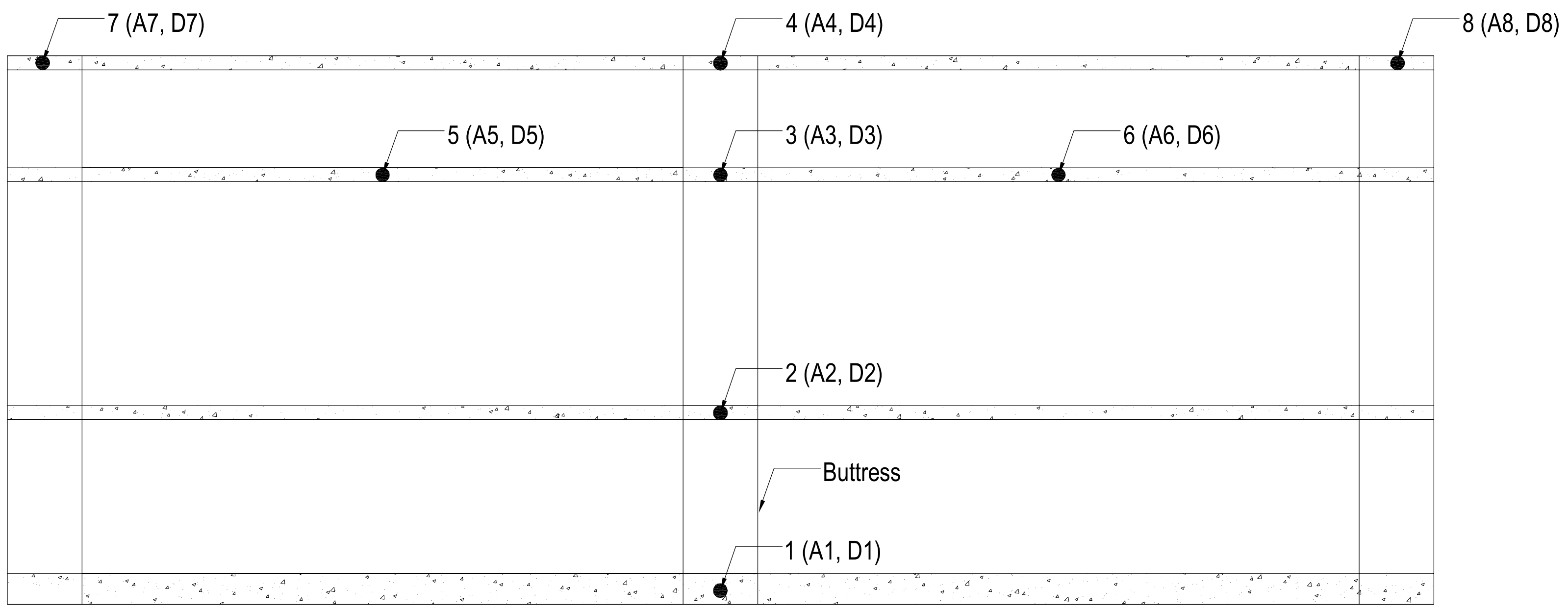
Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Scale Model) Type # 3	Instrumentation Plan - Ground Floor Plan (Longitudinal Direction)	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: October 2018
					Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 01 L



Direction of measurement normal to the paper.

Arrow shows direction of measurement.

Consultant Name: University of Engineering and Technology Peshawar.	Client Name: Asian Development Bank	Design Type: Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Scale Model) Type # 3	TITLE Instrumentation Plan - Eaves Level Plan (Longitudinal Direction)	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad; Drafted by: Engr. Attaur Rahman	Date: October 2018; Scale: Read As Shown; Dwg. No. 02 L

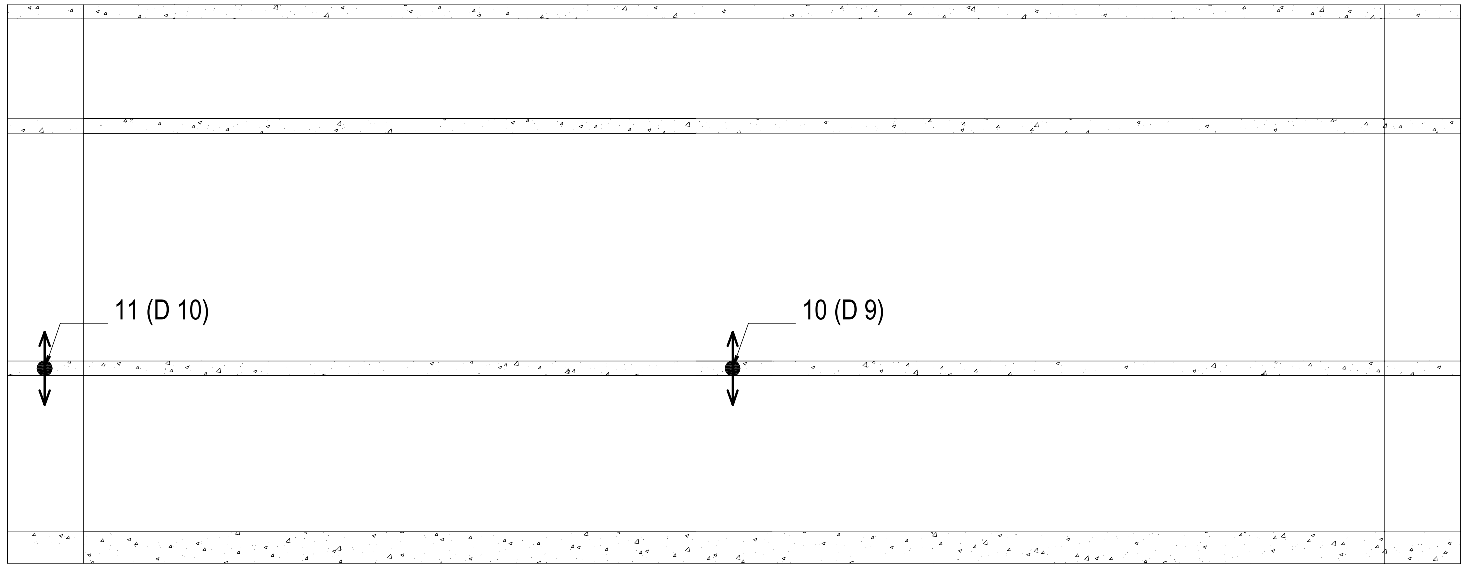


Direction of measurement normal to the paper.

Arrow shows direction of measurement.

Side Elevation
(Wall 3)

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Scale Model) Type # 3	Instrumentation Plan - Wall 3 (Longitudinal Direction)	Dr. Qaisar Ali Dr. Naveed Ahmad	Date: October 2018 Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 03 L



Direction of measurement normal to the paper.

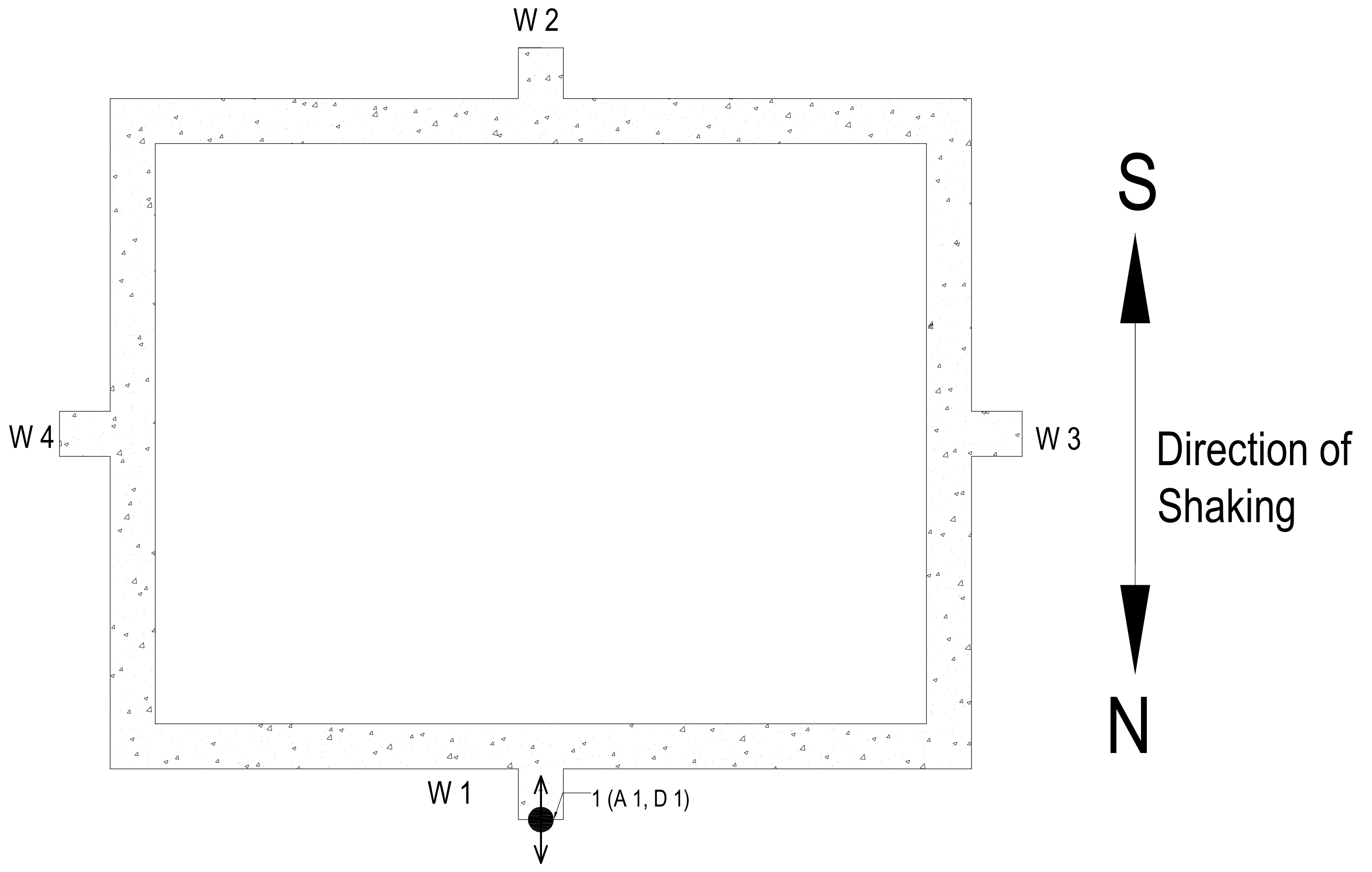
Arrow shows direction of measurement.

Side Elevation (Wall 4)

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	
University of Engineering and Technology Peshawar.	Asian Development Bank	Cement Stabilized Earth Brick in Cement Stabilized Mortar and RCC Bands (One Third Scale Model) Type # 3	Instrumentation Plan - Wall 4 (Longitudinal Direction)	Dr. Qaisar Ali Dr. Naveed Ahmad Drafted by: Engr. Attaur Rahman	Date: October 2018 Scale: Read As Shown Dwg. No. 04 L

Appendix F4 – Instrumentation Plan for 1/3rd Scale Model

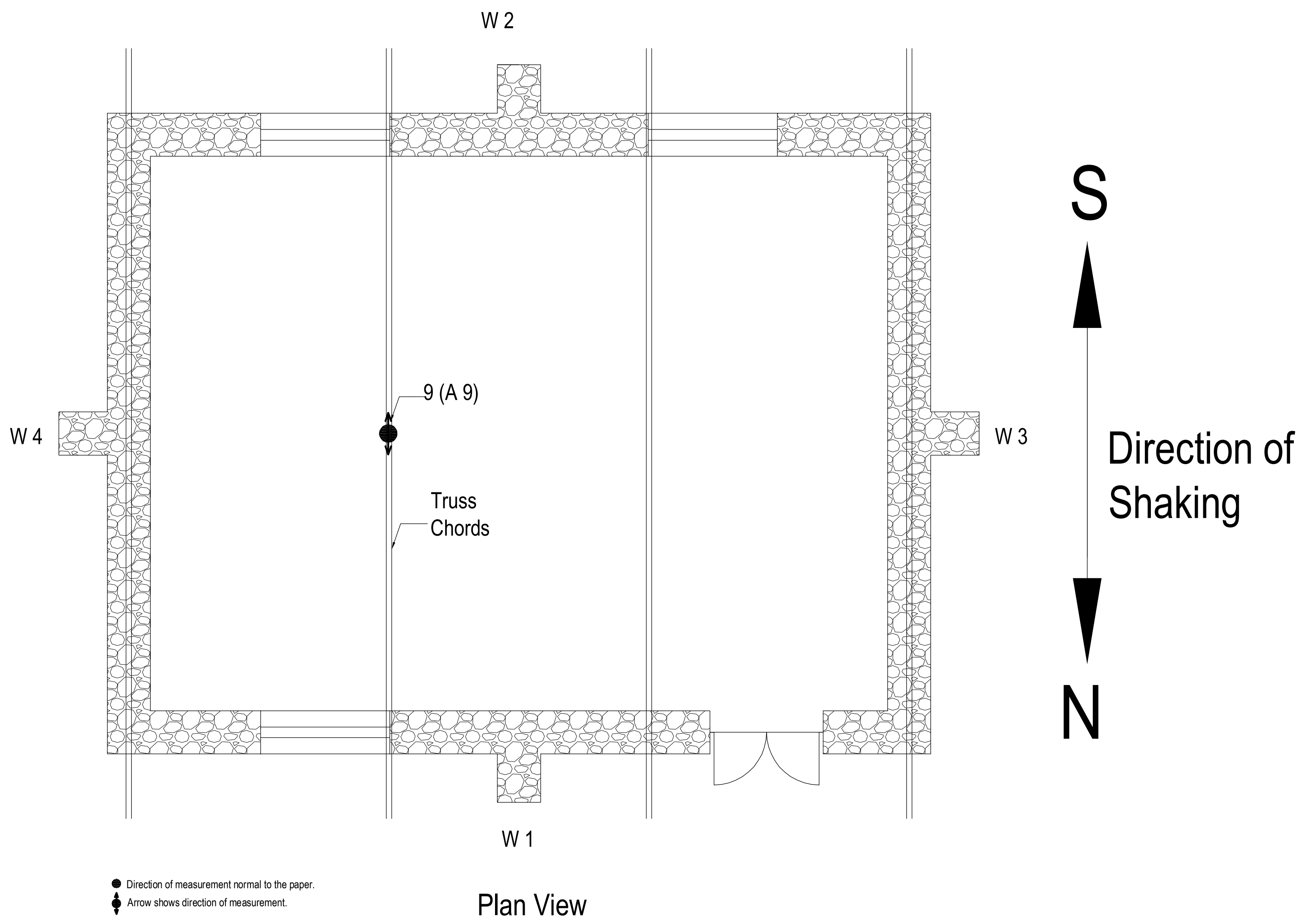
(Type Design 4)



Ground Floor Plan View

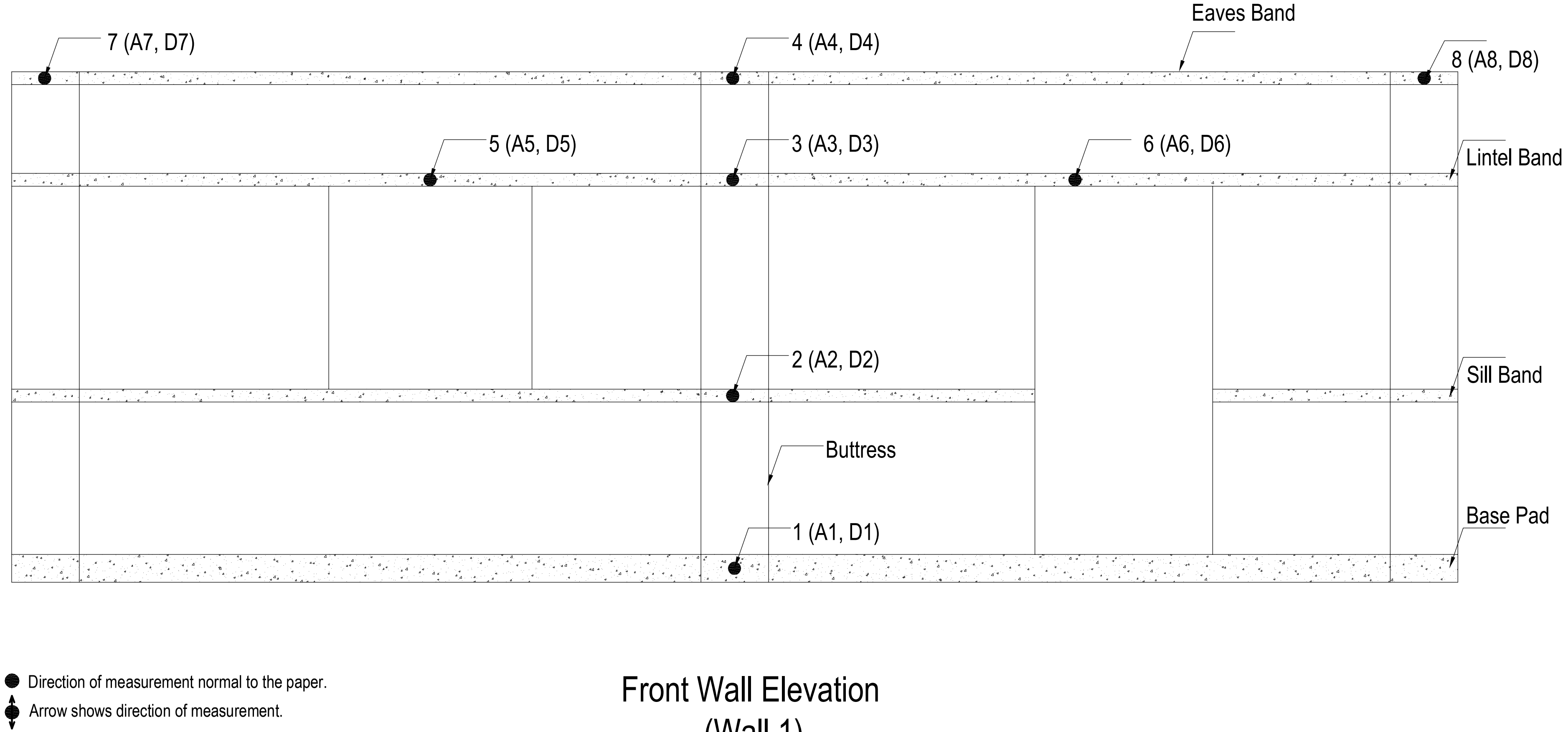
- Direction of measurement normal to the paper.
- Arrow shows direction of measurement.

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands & Wire Containment (One Third Scale Model) Type # 4	Instrumentation Plan - Ground Floor Plan	Dr. Qaisar Ali, Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 01



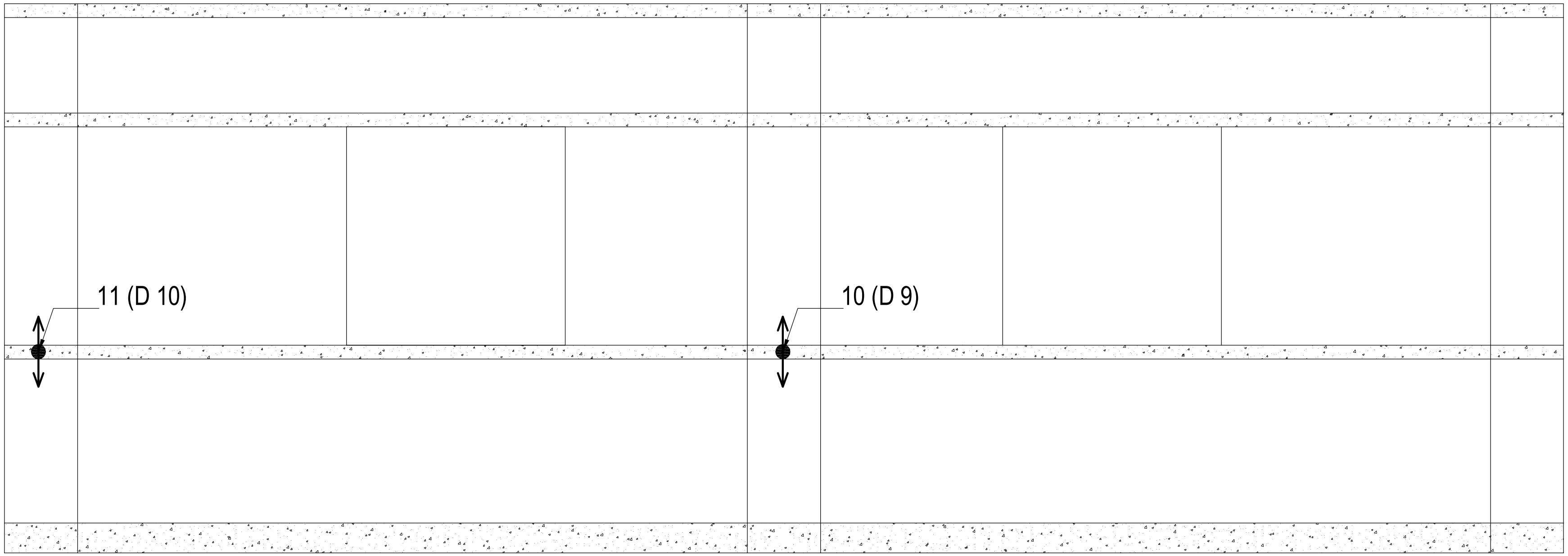
Plan View

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands & Wire Containment (One Third Scale Model) Type # 4	Instrumentation Plan - Eaves Level Plan	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 02



Front Wall Elevation
(Wall 1)

Consultant Name: University of Engineering and Technology Peshawar.	Client Name: Asian Development Bank	Design Type: Semidressed Stone Masonry with Timber Bands & Wire Containment (One Third Scale Model) Type # 4	TITLE Instrumentation Plan - Wall 1	Researchers: Dr. Qaisar Ali, Dr. Naveed Ahmad	Date: September 2018
					Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 03



Direction of measurement normal to the paper.
Arrow shows direction of measurement.

Back Wall Elevation (Wall 2)

Consultant Name:	Client Name:	Design Type:	TITLE	Researchers:	Date: September 2018
University of Engineering and Technology Peshawar.	Asian Development Bank	Semidressed Stone Masonry with Timber Bands & Wire Containment (One Third Scale Model) Type # 4	Instrumentation Plan - Wall 2	Dr. Qaisar Ali Dr. Naveed Ahmad	Scale: Read As Shown
				Drafted by: Engr. Attaur Rahman	Dwg. No. 04

Appendix G1 – Shake Table Test Protocol, Records of Damage and Table Acceleration - 2/3rd scale Model (Type Design 1)

Type 1, Two Third Test Protocol						Date: 03/03/2018
	2 Hz					
Run #	Sdmin	Voltage (mv)	f (Hz)	g	Remarks	Observations
	F1					
R1	1.5	50	2	0.024	Conducted	No significant damage observed.
	5 min					
R2	3	100	2	0.048	Conducted	No significant damage observed.
	5 min					
R3	6	200	2	0.097	Conducted	No significant damage observed.
	F2					
	10 min					
R4	12	400	2	0.193	Conducted	No significant damage observed.
	10 min					
R5	24	800	2	0.386	Conducted	No significant damage observed.
	F3					
	10 min					
	48	1600	2	0.773	Not Conducted	
	20 min					
	4 Hz					
	Sdmin	Voltage (mv)	f (Hz)	g	Remarks	Observations
R6	1.5	50	4	0.097	Conducted	No significant damage observed.
	5 min					
R7	3	100	4	0.193	Conducted	No significant damage observed.
	10 min					
R8	6	200	4	0.386	Conducted	1. Horizontal cracking below the eaves band observed in W4. 2. Very minor spalling of plaster observed on W4.
	F4					
	10 min					
R9	12	400	4	0.773	Conducted	1. In W4, cracks in the plaster widened and few spalling of mud plaster from the toe observed. 2. In W4, rocking observed at toe of buttress. 3. In W3, slight horizontal cracks at Eave band observed. 4. In W1, rocking at the base of buttress, spalling of mud plaster and few horizontal cracks at Eaves band observed.
	20 min					
	F5					
	6 Hz					
	Sdmin	Voltage (mv)	f (Hz)	g	Remarks	Observations
R10	1.5	50	6	0.217	Conducted	No futher significant damage observed.
	10 min					
R11	3	100	6	0.435	Conducted	1. In W3, minor cracking in the plaster observed.
	10 min					
	F6					
R12	6	200	6	0.869	Conducted	1. In W2, plaster cracking was observed. 2. In W4, spalling of mud plaster and widening of cracks observed.
	20 min					
	F7					
	8 Hz					
	Sdmin	Voltage (mv)	f (Hz)	g	Remarks	Observations
R13	1.5	50	8	0.386	Conducted	No futher significant damage observed.
	10 min					
R14	3	100	8	0.773	Conducted	1. In W4, further spalling of mud plaster observed.
	20 min					
	F8					
	10 Hz					
	Sdmin	Voltage (mv)	f (Hz)	g	Remarks	Observations
R15	1.5	50	10	0.604	Conducted	No futher significant damage observed.
	10 min					
	F9					
	12 Hz					
	Sdmin	Voltage (mv)	f (Hz)	g	Remarks	Observations
R16	1.5	50	12	0.869	Conducted	1. In W2, plaster cracking was observed.
	F10					
	4 Hz					
	Sdmin	Voltage (mv)	f (Hz)	g	Remarks	Observations
R17	12	400	4	0.773	Conducted	1. In W2, toe crushing at buttress observed. 2. In W3, minor sliding of eaves band observed. 3. In W4, considerable amount of spalling of mud plaster observed.
	F11					
	6 Hz					
	Sdmin	Voltage (mv)	f (Hz)	g	Remarks	Observations
R18	6	200	6	0.869	Conducted	1. In W3, cracks in the plaster aggravated, especially at the interface of eaves band and the wall. 2. In W4 further significant spalling of mud plaster observed.
	15 Seconds duration					
	F12					
	4 Hz					
	Sdmin	Voltage (mv)	f (Hz)	g	Remarks	Observations
R19	12	400	4	0.773	Conducted	1. In W4 further significant spalling of mud plaster observed.
	10 Seconds duration					
	4 Hz					
	Sdmin	Voltage (mv)	f (Hz)	g	Remarks	Observations
R20	12	400	4	0.773	Conducted	1. In W2, toe crushing at buttress and spalling mud plaster observed. 2. At the base of Splint in W2, spalling of concrete also observed. 3. In W3, cracks further widened and spalling of mud plaster also observed. 4. In W4 further significant spalling of mud plaster observed.
	20 Seconds duration					

Appendix G2 – Shake Table Test Protocol, Records of Damage and Table Acceleration - 2/3rd scale Model (Type Design 2)

Type 2 Two Third Model Test Protocol

Dated: 25/26-09-2018

Run #	Sdmin	Voltage (mv)	Time(Sec)	g	Damage observations	Remarks
Run #	2 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g	Damage observations	Remarks
	F1					
R1	1.5	50	5	0.024	No damage observed	Conducted
	5 min					
R2	3	100	5	0.048	No damage observed	Conducted
	5 min					
R3	6	200	5	0.097		Conducted
	F2					
	10 min					
R4	12	400	5	0.193	No damage observed	Conducted
	10 min					
R5	24	800	5	0.386	Flexure cracking of buttress with distributed horizontal cracks at the base. Some minor damage to plaster, table rotated and tilted (Wall # 2 side went down) during the shaking.	Conducted
	F3					
	10 min					
R6	48	1600	5	0.773		Not Conducted
	20 min					
	F4					
Run #	4 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R7	1.5	50	5	0.097	No further damage	Conducted
	5 min					
R8	3	100	5	0.193	Local OOP vibration of Wall # 1 seen at lintel level, cracking and plaster spalling at buttress base of Wall 1 and 2,	Conducted
	10 min					
R9	6	200	5	0.386	Resonance of building, rocking of buttresses B1 and B2 and minor rocking of Wall W1 and W2. Some cracking to wall # W4. Minor rocking of buttress B3 and B4, spalling of wall plasters in small chunks, minor damage to base of buttress B1, door lintel sagged.	Conducted
	F5					
	10 min					
R10	12	400	5	0.773	Severe resonance of building, rocking of all buttresses including B2 and B4 (may be due to torsional vibration of the table), plaster spalling, in-plane wall (W4) cracking and widening of cracks. Plaster spalling at base of buttress B1 and B2 due to toe crushing. Sagging of door/ window lintels, sliding of stone blocks past each other.	Conducted
	20 min					
	F6					
Run #	6 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R11	1.5	50	5	0.217	No further damage	Conducted
	10 min					
R12	3	100	5	0.435	No further damage	Conducted
	10 min					
	F7					
R13	6	200	5	0.869	Plaster spalling, sliding of masonry blocks past each other, no notable additional damage	Conducted
	20 min					
	F8					
Run #	8 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R14	1.5	50	5	0.386	No further notable damage	Conducted
	10 min					
R15	3	100	5	0.773	No further notable damage	Conducted
	20 min					
	F9					
Run #	10 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R16	1.5	50	5	0.604	No further notable damage	Conducted
	10 min					
	F10					
Run #	12 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R17	1.5	50	5	0.869	No further notable damage	Conducted
	F11					
					26/09/18	
Run #	6 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R18	6	200	5	0.869	Vibration of the building in all sort of direction like a card board box, plaster spalling, but no further notable structural damage	Conducted
	10 min					
	F12					
Run #	4 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R19	6	200	5	0.386	Plaster spalling, but further notable structural damage	Conducted
	5 min					
R20	12	400	5	0.773	Plaster spalling, but further notable structural damage	Conducted
	5 min					
R21	15	500	5	0.970	Severe sliding of stones in OOP wall, rocking of face loaded walls and buttresses (mainly W1 and W2, B1 ad B2), rest same as Run # R20.	Conducted
	10 min					
	F13					
Run #	2 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R22	24	800	5	0.386		Not Conducted
	10 min					
R23	48	1600	5	0.773		Not Conducted
	20 min					
R24	60	2000	5	0.97		Not Conducted
	10 min					
	20 min					
Run #	3 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R25	20	666.67	20	0.72	Intense shaking, but no further notable damage other than aggravated sliding of blocks past each other,	Conducted
	20 min					
R26	20	666.67	20	0.72	Intense shaking, but no further notable structural damage other than sliding of blocks past each other, distributed rocking of face loaded walls and buttresses (mainly W1, W2, B1, B2), damage to in-plane wall W4 (little damage to Wall W3)	Conducted
	10 min					
	F14					
Run #	4 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R21 Repeat	15	500	20	0.970	Long intense shaking, resonance. Severe sliding of blocks, loosening of one roof truss anchor to wall, OOP sliding of masonry blocks but basketed by containment mesh, wide cracks and distributed rocking of wall W4 observed but contained by containment mesh, a few small stones, typically ≈50mm size fell of walls (W4), buttress B1 bent vertically by ≈ 20mm, some local bulging of walls, stones below lintel slid off wall, but did not fall, wide cracks to walls (25-30mm wide) due to sliding of stone blocks. Immediate Occupancy	Conducted
	10 min					
	F15					

Notations

OOP: Out of plane
B1.....B4 Buttresses attached to wall 1 to wall 4
W1....W4 Walls W1 to W4

Notes:

Wall W4 suffered significantly more damage than W3 due to torsional vibration of the table. Wall W4 suffered nominal damage.
Significant movement of the stones was observed, however, the stones were basketed by containment mesh which prevented dislodging of stones.
Wide cracks in the walls along mortar beds developed during the shaking, but would close once table shaking ceased.
Distributed cracking along the bed joint and sliding of the stone blocks past each other was observed in early stage intense shaking.
No separation between bands and wall was observed. The plaster to bands generally did not spall even at intense shaking other than near buttresses

Run R10 initiated major damage to the model, however, as the in-plane wall damages was sliding mode, any intense shaking was able to aggravate the distributed sliding and widening of gap between the stone blocks only, the shaking could not lead to global failure as at no point the OOP walls were detached from the in-plane walls..

It is possible that the damages noted after the Run # 21R may have occurred during Run R18-R26 at various intensities, however, these could not be noted because the shaking table was in operation and was not permitted to get closer to the table because of Health and Safety reasons.

Appendix G3 – Shake Table Test Protocol, Records of Damage and Table Acceleration - 2/3rd scale Model (Type Design 3)

Type 3 Two Third Model Test Protocol (24_10_2018)						
Run #	2 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g	Damage observations	Remarks
	F1					
R1	1.5	50	5	0.024	No significant damage observed	Conducted
	5 min					
R2	3	100	5	0.048	No significant damage observed	Conducted
	5 min					
R3	6	200	5	0.097	No significant damage observed	Conducted
	F2					
	10 min					
R4	12	400	5	0.193	No significant damage observed	Conducted
	10 min					
R5	24	800	5	0.386	No significant damage observed	Conducted
	F3					
	10 min					
R6	48	1600	5	0.773		Not Conducted
	20 min					
	F4					
Run #	4 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g	Damage observations	Remarks
R7	1.5	50	5	0.097	No significant damage observed	Conducted
	5 min					
R8	3	100	5	0.193	No significant damage observed	Conducted
	10 min					
R9	6	200	5	0.386	Minor cracks appeared in the mortar just below the sill level on Wall 2 near the door.	Conducted
	F5					
	10 min					
R10	12	400	5	0.773	**1.** Horizontal cracks on Wall 3 and Wall 4 observed at location b/w sill and Lintel **2.** Slight diagonal cracks also observed in the in-plane walls (W3 and W4) at location b/w sill and lintel level. **3.** Brick crushing in Buttress of Wall 3 observed.	Conducted
	20 min					
	F6					
Run #	6 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g	Damage observations	Remarks
R11	1.5	50	5	0.217	No further significant damages observed.	Conducted
	10 min					
R12	3	100	5	0.435	Rocking of buttress on Wall at Lintel level observed.	Conducted
	10 min					
	F7					
R13	6	200	5	0.869	**1.** Horizontal cracks further widened and its number increased. **2.** B/w lintel and sill level horizontal and diagonal cracks were observed in the inplance Walls (W3 and W4). **3.** Due to out-of-plane action sliding of bricks were observed in Wall 3 and Wall 4. **4.** Rocking of buttress between lintel and base in Wall 1 was observed. **5.** Diagonal cracks were observed b/w sill and lintel level in Wall 1.	Conducted
	20 min					
	F8					
Run #	8 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g	Damage observations	Remarks
R14	1.5	50	5	0.386	No further significant damages observed.	Conducted
	10 min					
R15	3	100	5	0.773	Falling of one brick observed in Wall 4.	Conducted
	20 min					
	F9					
Run #	10 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g	Damage observations	Remarks
R16	1.5	50	5	0.604	No further significant damages observed.	Conducted
	10 min					
	F10					
Run #	12 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g	Damage observations	Remarks
R17	1.5	50	5	0.869	No further significant damages observed.	Conducted
	F11					
Run #	6 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g	Damage observations	Remarks
R18	6	200	5	0.869	**1.** Splitting observed at the toe of buttress of Wall 1. **2.** Wedge separation at below the lintel level in Wall 1 buttress observed. **3.** Sliding out of further units of bricks are observed in Wall 3 and Wall 4. **4.** After R-18, A1, A2, D1, D2 and D13 were removed to avoid damage to instruments.	Conducted
	10 min					
	F12					
Run #	4 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g	Damage observations	Remarks
R19	6	200	5	0.386	No further significant damages observed.	Conducted
	5 min					
R20	12	400	5	0.773	**1.** Toe crushing of Wall 1 buttress and separation of wedge from Wall 1 buttress observed, **2.** Corner failure b/w W1 and W4 just below the lintel level observed. **3.** After R21, D5, A10, A5 and D10 were removed to avoid damage to instuments.	Conducted
	5 min					
R21	15	500	5	0.970	1. Out-of-plane failure of bricks at corner just below lintel band of Wall 1 and Wall 4 observed. 2. Out-of-plane sliding of brick units of inplane wall 4 right below the lintel band observed.	Conducted
	10 min					
	F13					
Run #	2 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g	Damage observations	Remarks
R22	24	800	5	0.386		Not Conducted
	10 min					
R23	48	1600	5	0.773		Not Conducted
	20 min					
R24	60	2000	5	0.97		Not Conducted
	10 min					
	20 min					
Run #	3 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g	Damage observations	Remarks
R25	20	666.67	20	0.72		Not Conducted
	20 min					
R26	20	666.67	20	0.72		Not Conducted
	10 min					
	F14					
Run #	4 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g	Damage observations	Remarks
R21 Repeat	15	500	20	0.970		Not Conducted
	10 min					
	F15					

Appendix G3-R – Shake Table Test Protocol, Records of Damage and Table Acceleration - 2/3rd scale Model (Type Design 3 – Repaired Model)

Type Design # 3 Two Third Scale Model Test Protocol (Retesting after repair)						Date **27/11/18**
Run #	**2 Hz**					
	Sdmin	**Voltage (mv)**	**Time(Sec)**	**g**	**Damage observations**	**Remarks**
	F1					
R1	1.5	50	5	0.024	No damage	
	5 min					
R2	3	100	5	0.048	No damage	
	5 min					
R3	6	200	5	0.097	No damage	
	F2					
	10 min					
R4	12	400	5	0.193	No damage	
	10 min					
R5	24	800	5	0.386	Spalling of mortar (both in-plane and out-of-plane walls), minor cracking of masonry	
	F3					
	10 min					
R6	48	1600	5	0.773	Not conducted	
	20 min					
	F4					
Run #	**4 Hz**					
	Sdmin	**Voltage (mv)**	**Time(Sec)**	**g**		**Remarks**
R7	1.5	50	5	0.097	No further damage	
	5 min					
R8	3	100	5	0.193	Spalling of mortar (both in-plane and out-of-plane walls), minor sliding along mortar layers, vertical crack to Wall W4	
	10 min					
R9	6	200	5	0.386	Diagonal cracks to wall W4, separation between band and masonry wall W4, sliding of masonry wall below eaves band (wall W4)	
	F5					
	10 min					
R10	12	400	5	0.773	Extensive damage to masonry walls, spalling of bricks, separation of bands from masonry walls (W1 and W4), no damage to bands, damage to wall corners, expulsion of bricks at corners (wall W2 and W4), fal of	**Conducted after R15, end of the test**
	20 min					
	F6					

Run #	6 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R11	1.5	50	5	0.217	OOP walls flopping (OOP vibration) due to out of plane vertical bending, no further damage to building	
	10 min					
R12	3	100	5	0.435	No conducted	
	10 min					
	F7					
R13	6	200	5	0.869	No further damage, some minor spalling, flipping of OOP walls	
	20 min					
	F8					
Run #	8 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R14	1.5	50	5	0.386	No further damage other than wall W2 (brick spalling from below lintel level)	
	10 min					
R15	3	100	5	0.773	Spalling of bricks (W2), expulsion of bricks from W4, further cracking of walls, fall of masonry from door jamb of Wall W3	Conducted after R
	20 min					
	F9					
Run #	10 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R16	1.5	50	5	0.604	No further damage	
	10 min					
	F10					
Run #	12 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R17	1.5	50	5	0.869	Not conducted	
	F11					

Run #	6 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R18	6	200	5	0.869	Not conducted	
	10 min					
	F12					
Run #	4 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R19	6	200	5	0.386	Not conducted	
	5 min					
R20	12	400	5	0.773	Not conducted	
	5 min					
R21	15	500	5	0.970	Not conducted	
	10 min					
	F13					
Run #	2 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R22	24	800	5	0.386	No further damage	
	10 min					
R23	48	1600	5	0.773	No conducted	
	20 min					
R24	60	2000	5	0.97	Not conducted	
	10 min					
	20 min					
Run #	3 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R25	20	666.67	20	0.72	Not conducted	
	20 min					
R26	20	666.67	20	0.72	Not conducted	
	10 min					
	F14					
Run #	4 Hz					
	Sdmin	Voltage (mv)	Time(Sec)	g		Remarks
R21 Repeat	15	500	20	0.970	Not conducted	
	10 min					
	F15					

Appendix G4 – Shake Table Test Protocol, Records of Damage and Table Acceleration - 2/3rd scale Model (Type Design 4)

Type 4 Two Third Model Test Protocol						
Run #	**2 Hz**					
	Sdmin	**Voltage (mv)**	**Time(Sec)**	**g**	**Damage Observations**	**Remarks**
	F1					
R1	1.5	50	5	0.024	No Damage Observed	**Conducted**
	5 min					
R2	3	100	5	0.048	No Damage Observed	**Conducted**
	5 min					
R3	6	200	5	0.097	No Damage Observed	**Conducted**
	F2					
	10 min					
R4	12	400	5	0.193	No Damage Observed	**Conducted**
	10 min					
R5	24	800	5	0.386	No Damage Observed	**Conducted**
	F3					
	10 min					
R6	48	1600	5	0.773	Observed observations are as follows, 1. Spalling of Plaster 2. Horizontal Sliding of Timber Bands 3. Opening of connections of timber bands right above buttresses 4. Detachment of Purlins from Truss Chord at corner of Wall 3 and 4. 5. The detached Purlin is connected again. 6. Huge rocking was observed in buttress of Wall 1 7. Buckling of Containment wires is observed	**Conducted**
	20 min					
	F4					
Run #	**4 Hz**					
	Sdmin	**Voltage (mv)**	**Time(Sec)**	**g**	**Damage Observations**	**Remarks**
R7	1.5	50	5	0.097	Spalling of Mud Mortar observed	**Conducted**
	5 min					
R8	3	100	5	0.193	1. Significant out of plane deflection in Wall 1 and Wall 2 in the masonry panel b/w Lintel and Eaves Level at the mid of wall is observed. 2. Accelerometers (A1, A2, A3, A4) and Displacement Transducers (D1, D2, D3, D4), installed on buttress of Wall 1, is removed.	**Conducted**
	10 min					
R9	6	200	5	0.386	Spalling of Mud Mortar observed	**Conducted**
	F5					
	10 min					
R10	12	400	5	0.773	Spalling of Plaster at Band Level is observed	**Conducted**
	20 min					
	F6					
Run #	**6 Hz**					
	Sdmin	**Voltage (mv)**	**Time(Sec)**	**g**	**Damage Observations**	**Remarks**
R11	1.5	50	5	0.217	No Damage Observed	**Conducted**
	10 min					
R12	3	100	5	0.435	Spalling of Mud Mortar observed	**Conducted**
	10 min					
	F7					
R13	6	200	5	0.869	Spalling of Mud Mortar observed	**Conducted**
	20 min					
	F8					
Run #	**8 Hz**					
	Sdmin	**Voltage (mv)**	**Time(Sec)**	**g**	**Damage Observations**	**Remarks**
	1.5	50	5	0.386		**Not Conducted**
	10 min					
	3	100	5	0.773		**Not Conducted**
	20 min					
	F9					
Run #	**10 Hz**					
	Sdmin	**Voltage (mv)**	**Time(Sec)**	**g**	**Damage Observations**	**Remarks**
	1.5	50	5	0.604		**Not Conducted**
	10 min					
	F10					
Run #	**12 Hz**					
	Sdmin	**Voltage (mv)**	**Time(Sec)**	**g**	**Damage Observations**	**Remarks**
	1.5	50	5	0.869		**Not Conducted**
	F11					
Run #	**6 Hz**					
	Sdmin	**Voltage (mv)**	**Time(Sec)**	**g**	**Damage Observations**	**Remarks**
	6	200	5	0.869		**Not Conducted**
	10 min					
	F12					
Run #	**4 Hz**					
	Sdmin	**Voltage (mv)**	**Time(Sec)**	**g**	**Damage Observations**	**Remarks**
R14	6	200	5	0.386	Spalling of Mud Mortar observed	**Conducted**
	5 min					
R15	12	400	5	0.773	Spalling of Mud Mortar observed	**Conducted**
	5 min					
R16	15	500	5	0.970	Few stones in buttress of Wall 1 and Wall 4 were displaced but not fallen. Only few stones have fallen.	**Conducted**
	10 min					
R17=R16 Repeat	15	500	5	0.970	Few stones were fallen particularly from buttress at Lintel level from Wall 1 and Wall 4.	**Conducted**
	F13					
Run #	**2 Hz**					
	Sdmin	**Voltage (mv)**	**Time(Sec)**	**g**	**Damage Observations**	**Remarks**
	24	800	5	0.386		**Not Conducted**
	F14					
	10 min					
	48	1600	5	0.773		**Not Conducted**
	20 min					
	60	2000	5	0.97		**Not Conducted**
	10 min					
	F15					

Appendix H1 – Photographic Images of Damage to 2/3rd Scale Model (Type Design 1)

Figure 1: Pre-test Picture of Model

Figure 2: Pre-test Picture of Model

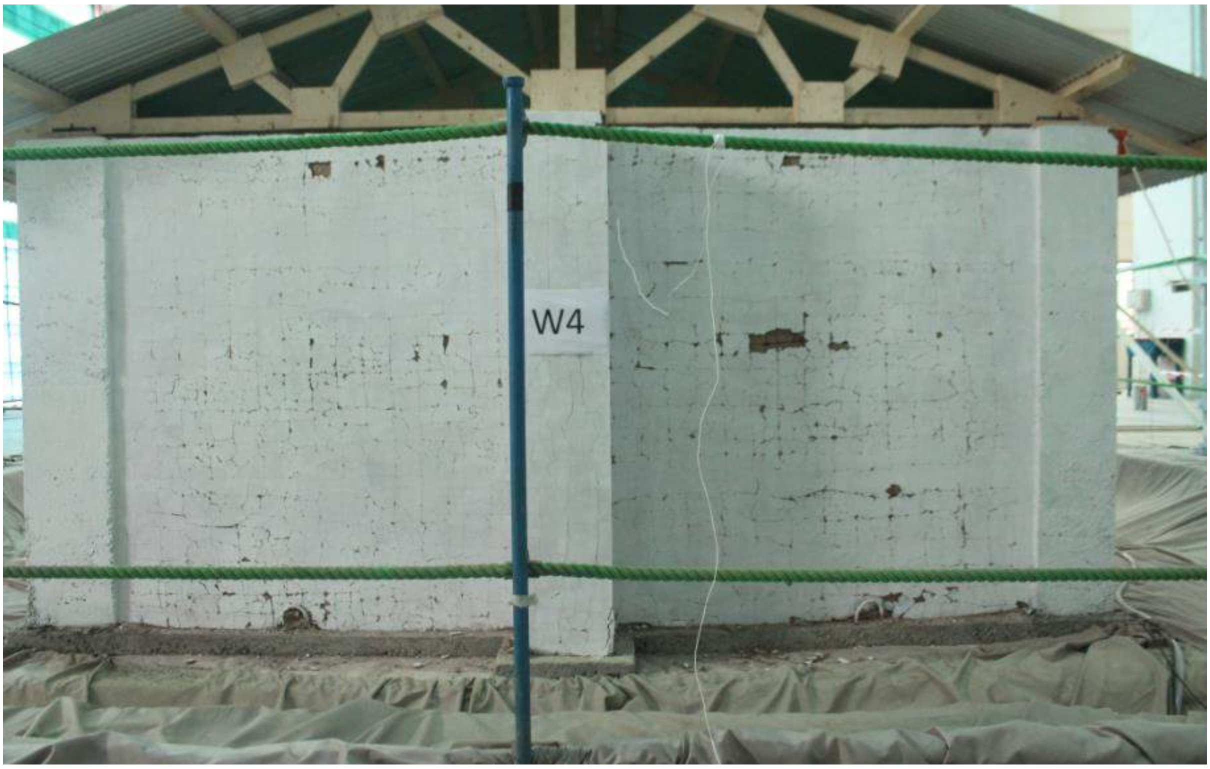


Figure 3: Run 9, 4 Hz frequency, 12 mm displacement

Figure 4: Run 9, 4 Hz frequency, 12 mm displacement

Figure 5: Run 12, 6 Hz frequency, 6 mm displacement

Figure 6: Run 12, 6 Hz frequency, 6 mm displacement

Figure 7: Run 16, 12 Hz frequency, 1.5 mm displacement

Figure 8: Run 16, 12 Hz frequency, 1.5 mm displacement

Figure 9: Run 18, 6 Hz frequency, 6 mm displacement

Figure 10: Run 18, 6 Hz frequency, 6 mm displacement

Figure 11: Run 18, 6 Hz frequency, 6 mm displacement

Figure 12: Run 18, 6 Hz frequency, 6 mm displacement

Figure 13: Run 20, 4 Hz frequency, 12 mm displacement

Figure 14: Run 20, 4 Hz frequency, 12 mm displacement

Figure 15: Run 20, 4 Hz frequency, 12 mm displacement

Figure 16: Run 20, 4 Hz frequency, 12 mm displacement

Appendix H2 – Photographic Images of Damage to 2/3rd Scale Model (Type Design 2)

Figure 1: Pretest Picture of Model

Figure 2: Run 9, 4 Hz frequency, 6mm displacement

Figure 3: Run 9, 4 Hz frequency, 6mm displacement

Figure 4: Run 9, 4 Hz frequency, 6mm displacement

Figure 5: Run 21, 4 Hz frequency, 15mm displacement

Figure 6: Run 21, 4 Hz frequency, 15mm displacement

Figure 7: Run 21, 4 Hz frequency, 15mm displacement

Figure 8: Run 26, 3 Hz frequency, 20mm displacement

Figure 9: Run 26, 3 Hz frequency, 20mm displacement

Figure 10: Run 26, 3 Hz frequency, 20mm displacement

Figure 11: Run 26, 3 Hz frequency, 20mm displacement

Figure 12: Run 26, 3 Hz frequency, 20mm displacement

Figure 13: Run 21-Repeat, 4 Hz frequency, 15mm displacement

Figure 14: Run 21-Repeat, 4 Hz frequency, 15mm displacement

Figure 15: Run 21-Repeat, 4 Hz frequency, 15mm displacement

Figure 16: Run 21-Repeat, 4 Hz frequency, 15mm displacement

Appendix H3 – Photographic Images of Damage to 2/3rd Scale Model (Type Design 3)

Figure 1: Pre-test Picture of Model

Figure2: Pre-test Picture of Model

Figure 3: Run 13, 6 Hz frequency, 6 mm displacement

Figure 4: Run 13, 6 Hz frequency, 6 mm displacement

Figure 5: Run 13, 6 Hz frequency, 6 mm displacement

Figure 6: Run 13, 6 Hz frequency, 6 mm displacement

Figure 7: Run 18, 6 Hz frequency, 6 mm displacement

Figure 8: Run 18, 6 Hz frequency, 6 mm displacement

Figure 9: Run 18, 6 Hz frequency, 6 mm displacement

Figure 10: Run 18, 6 Hz frequency, 6 mm displacement

Figure 11: Run 20, 4 Hz frequency, 12 mm displacement

Figure 12: Run 20, 4 Hz frequency, 12 mm displacement

Figure 13: Run 20, 4 Hz frequency, 12 mm displacement

Figure 14: Run 20, 4 Hz frequency, 12 mm displacement

Figure 15: Run 21, 4 Hz frequency, 15mm displacement

Figure 16: Run 21, 4 Hz frequency, 15mm displacement

Figure 17: Run 21, 4 Hz frequency, 15mm displacement

Figure 18: Run 21, 4 Hz frequency, 15mm displacement

Appendix H4 – Photographic Images of Damage to 2/3rd Scale Model (Type Design 4)

Figure 1: Pretest Picture of Model

Figure 2: Run 6, 2 Hz frequency, 48 mm displacement

Figure 3:Run 6, 2 Hz frequency, 48 mm displacement

Figure 4:Run 6, 2 Hz frequency, 48 mm displacement

Figure 5:Run 6, 2 Hz frequency, 48 mm displacement

Figure 6:Run 6, 2 Hz frequency, 48 mm displacement

Figure 7:Run 6, 2 Hz frequency, 48 mm displacement

Figure 8: Run-10, 4 Hz frequency, 12 mm displacement

Figure 9:Run-10, 4 Hz frequency, 12 mm displacement

Figure 10: Run-15, 4 Hz frequency, 12 mm displacement

Figure 11: Run-17, 4 Hz frequency, 15 mm displacement

Figure 12: Run-17, 4 Hz frequency, 15 mm displacement

Appendix I1 – Shake Table Test Protocol, Records of Damage and Table Acceleration - 1/3rd scale Model (Type Design 1)

Shake Table Test, Type 1 One Third			
EQ	**%age**	**Remarks**	**Damage Observations**
EQ1	F1	Conducted	
	Self Check 1	Conducted	1. No significant damage observed
	Self Check 2	Conducted	1. No significant damage observed
	F2	Conducted	
	5	Conducted	1. No significant damage observed
	10	Conducted	1. No significant damage observed
	20	Conducted	1. No significant damage observed
	30	Conducted	1. Minor cracks in plaster of W3 observed.
	40	Conducted	1. No further significant damage observed
	50	Conducted	1. No further significant damage observed
	F3	Conducted	
	60	Conducted	1. No further significant damage observed
	70	Conducted	1. No further significant damage observed
	80	Conducted	1. No further significant damage observed
	90	Conducted	1. No further significant damage observed
	100	Conducted	1. No further significant damage observed
EQ2	F4	Conducted	
	Self Check 3	Conducted	1. No further significant damage observed
	F5	Conducted	
	60	Conducted	1. No further significant damage observed
	70	Conducted	1. No further significant damage observed
	80	Conducted	1. In W4, cracks in the plaster observed.
	F6	Conducted	
	90	Conducted	1. Toe crushing at buttress of W1 observed. 2. Cracks in plaster of W4 widened. 3. In W3, cracks widened further.
	F7	Conducted	
	100	Conducted	1. Cracks in W3 widened further, and also spalling of mud plaster.
	F8	Conducted	
EQ3	60	Conducted	1. No further significant damage observed
	70	Conducted	1. Spalling of plaster from W4 observed.
	80	Conducted	
	90	Conducted	1. Further spalling of plaster from W4 observed. 2. Rocking observed at the base of W1.
	100	Conducted	1. Further spalling of plaster from W4 observed. 2. Toe crushing at buttress of W4 observed. 3. Sever spalling of mud plaster from W3 observed.
	F9	Conducted	
EQ4	Self Check 4	Conducted	1. Cracks in W4 further widened and spalling of plaster was also observed. 2. Further spalling of plaster from W3 observed.
	100-1	Conducted	1. Further spalling of plaster of W4 and toe crushing at buttress of W1 observed.
	100-2	Conducted	1. Further spalling of plaster from W3 and W4 observed.
	F10	Conducted	
EQ5 50%Containment W3 No Containment W4	60	Conducted	1. Falling of few stone units from W4 observed.
	70	Conducted	1. Further falling of stone units from W4 observed. 2. Sliding of Lintel band in W3 observed.
	80	Conducted	1. Further falling of stone units from W4 observed.
	90	Conducted	1. Severe falling of stone units observed from W4.
	100	Conducted	1. Severe falling of stone units observed from W4.
Sine Sweep		Not Conducted	

Appendix I2 – Shake Table Test Protocol, Records of Damage and Table Acceleration - 1/3rd scale Model (Type Design 2)

Type 2, One Third, Shake Table Test Protocols [26/30-10-2018]				
Time History	%age	Excitation Direction	Observations	Remarks
EQ1	F1/ Pulse Test	Transverse- Direction Excitation		Not Conducted
	Self Check 1		**1.** Out of plane wall (W-1) rocking at the base of buttress observed. **2.** Horizontal cracks observed right below the lintel level on W-1 and W-2.	Conducted
	F2/ Pulse Test			Conducted
	5		No further significant damage observed.	Conducted
	10		No further significant damage observed.	Conducted
	20		No further significant damage observed.	Conducted
	30		No further significant damage observed.	Conducted
	40		No further significant damage observed.	Conducted
	50		**1.** Further slight crack observed in the W-1 and W-2 wall b/w lintel and eaves level following containment pattern.	Conducted
	F3/ Pulse Test			Conducted
	60		No further significant damage observed.	Conducted
	70		No further significant damage observed.	Conducted
	80		No further significant damage observed.	Conducted
	90		No further significant damage observed.	Conducted
	100		No further significant damage observed.	Conducted
	F4/ Pulse Test			Conducted
EQ2	Self Check 2	Transverse- Direction Excitation	**1.** Rocking of buttress at W-1 observed.	Conducted
	60		**1.** Diagonal cracks in W-1 b/w lintel and eaves level observed b/w buttress and door. **2.** Cracks further aggravated b/w lintel and eaves level on W-2.	Conducted
	F5/ Pulse Test			Conducted
	70		**1.** Spalling of plaster from W-1 and W-2 b/w lintel and eaves level observed. **2.** Rocking of buttress of W-1 and W-2 observed. Spallling of Plaster at toe of W-2 observed. **3.** Horizontal ctracks observed in W-1 and W-2 below sill level.	Conducted
	80		No further significant damage observed.	Conducted
	F6/ Pulse Test			Conducted
	90		No further significant damage observed.	Conducted
	F7/ Pulse Test			Conducted
	100		**1.** Significant rocking has been observed for W-1 and W-**2.** Toe crushing of buttress and near the door on W-1 has been observed. Similar toe crushing of W-2 has also been observed. **3.** Horizontal sliding is also observed at the base level. **4.** Slight cracks have been also observed in the inplane walls.	Conducted
	F8/ Pulse Test			Conducted
EQ1	F9/ Pulse Test	Longitudinal- Direction Excitation		Conducted
	Self Check 3		**1.** Buttress rocking of W-3 and W-4 due to out-of-plane rocking of Walls observed with significant deflection.	Conducted
	F10/ Pulse Test		No further significant damage observed.	Conducted
	5		No further significant damage observed.	Conducted
	10		No further significant damage observed.	Conducted
	20		No further significant damage observed.	Conducted
	30		No further significant damage observed.	Conducted
	40			Not Conducted
	50			Not Conducted
	F11/ Pulse Test			Not Conducted
	60			Not Conducted
	70			Not Conducted
	80			Not Conducted
	90			Not Conducted
	100			Not Conducted
	F12/ Pulse Test			Not Conducted
EQ2	Self Check 4	Longitudinal- Direction Excitation		Not Conducted
	F13/ Pulse Test			Not Conducted
	60			Not Conducted
	70			Not Conducted
	80			Not Conducted
	F14/ Pulse Test			Not Conducted
	90			Not Conducted
	F15/ Pulse Test			Not Conducted
	100			Not Conducted
	F16/ Pulse Test			Not Conducted

Appendix I2-R – Shake Table Test Protocol, Records of Damage and Table Acceleration - 1/3rd scale Model (Type Design 2 - Repaired)

Type 2, One Third, Shake Table Test Protocols, Direction of shaking: Transverse (retest after repair) [29-11-2018]			
Time History	**%age**	**Observations**	**Remarks**
EQ1	**F1/ Pulse Test**	Rocking of buttresses of OOP wall	
	Self Check 1	Rocking of buttresses of OOP wall	Unintended strong shaking
	F2/ Pulse Test		
	5	No further damage	
	10	No further damage	
	20	No further damage	
	30	No further damage other than minor rocking of buttresses of OOP wall (Wall W1)	
	40	No further damage other than minor rocking of buttresses of OOP wall (Wall W1)	
	50	No further damage other than minor rocking of buttresses of OOP wall (Wall W1)	
	F3/ Pulse Test	No further damage other than minor rocking of buttresses of OOP wall (Wall W1)	
	60	No further damage other than minor rocking of buttresses of OOP wall (Wall W1)	
	70		
	80	No further damage other than minor rocking of buttresses of OOP wall (Wall W1)	
	90	No further damage other than progression of earlier damages, minor rocking of buttresses of OOP wall (Wall W1),	
	100	No further damage other than progression of earlier damages, minor rocking of buttresses of OOP wall (Wall W1),	
	F4/ Pulse Test		
EQ2	Self Check 2	No further damage other than progression of earlier damages, minor rocking of buttresses of OOP wall (Wall W1), plaster spalling,	
	60	No further damage other than progression of earlier damages, minor rocking of buttresses of OOP wall (Wall W1),	
	F5/ Pulse Test		
	70	No further damage other than progression of earlier damages, minor rocking of buttresses of OOP wall (Wall W1), plaster spalling,	
	80	No further damage other than progression of earlier damages, minor rocking of buttresses of OOP wall (Wall W1), plaster spalling, toe crushing (delamination of stones, movement of stone blocks, pushout of mortar)	
	F6/ Pulse Test		
	90	No further damage other than progression of earlier damages, minor rocking of buttresses of OOP wall (Wall W1), plaster spalling, further toe crushing (delamination of stones, movement of stone blocks, pushout of mortar)	
	F7/ Pulse Test		
	100-1	Extensive rocking of buttresses and walls (both in-plane and OOP), damage to connection between walls and trusses (particularly the end ones)	Violent shaking
	F8/ Pulse Test		
	100-2	Extensive rocking of buttresses and walls (both in-plane and OOP), damage to connection between walls and trusses (particularly the end ones), toe cursing	Violent shaking
KIRT_EW	Self Check 3		
	F9/ Pulse test		
	100%	Heavy degradation of model, rocking damage to spandrel	
After removal of 50% and 100% of wire containment			
EQ1-R	**100%**	Softening of spandrels in-plane walls (above door and windows), violent rocking of buttresses	
EQ1-R	**100%-2**	Softening of spenders of in-plane walls (above door and windows), violent rocking of buttresses	
	Self Check 5		
EQ2-R	**80%**	No further damage other than spalling of more mortar	
EQ2-R	**90%**	No further damage other than spalling of more mortar	
EQ2-R	**100%**	No further damage	
EQ2-R	**100%-1**		
EQ2-R	**100%-2**	Expulsion of stones from 100% containment removed areas	
EQ2-R	**100%-3**	Extensive expulsion and movement of stones from wall with no containment, very little movement or expulsion of stones from wall with 50% containment, extensive rocking of buttresses, damage of door spandrels, failure of connection between wall and truss connections,	
Notations			
OOP:	Out of plane		

Appendix I3 – Shake Table Test Protocol, Records of Damage and Table Acceleration - 1/3rd scale Model (Type Design 3)

	F1/ Pulse Test			**Conducted**
	Self Check 1		**1**. Significant in-plane cracks developed in the in-plane walls i.e W3 and W4. **2**. Horizontal Sliding observed at Sill and Lintel level bands. **3**. Horizontal (Shear) sliding were also observed b/w Sill and Lintel of W4. **4**. Toe crushing at Buttresses of W1 and W3 also observed.	**Conducted**
	F2/ Pulse Test			**Conducted**
EQ1	5	**Transverse- Direction Excitation**	No further significant damage observed	**Conducted**
	10		No further significant damage observed	**Conducted**
	20		No further significant damage observed	**Conducted**
	30		No further significant damage observed	**Conducted**
	40		No further significant damage observed	**Conducted**
	50		No further significant damage observed	**Conducted**
	F3/ Pulse Test			**Conducted**
	60		No further significant damage observed	**Conducted**
	70		No further significant damage observed	**Conducted**
	80		No further significant damage observed	**Conducted**
	90		No further significant damage observed	**Conducted**
	100		No further significant damage observed	**Conducted**
	F4/ Pulse Test			**Conducted**
EQ2	Self Check 2	**Transverse- Direction Excitation**	No further significant damage observed	**Conducted**
	F5/ Pulse Test			**Conducted**
	60		No further significant damage observed	**Conducted**
	70		1. In 70-80%, Falling of bricks from W3 just above Sill level observed due to horizontal shear crack and at toe end of butresses observed.	**Conducted**
	80			**Conducted**
	F6/ Pulse Test			**Conducted**
	90		No further significant damage observed	**Conducted**
	F7/ Pulse Test			**Conducted**
	100		**1.** Further falling of Brick units from buttress of W3 at the horizontal shear crack observed. **2**. Corner wedge separation at toe of W3 and W4 observed. **3**. Inplane cracks both on W3 and W4 aggravated, however the extent of damage was high on wall having no buttress (W4). **4**. Sliding out of brick units from inplane wall W4 observed b/w Sill and Lintel level (at the stitch location).	**Conducted**
	F8/ Pulse Test			**Conducted**
	F9/ Pulse Test			**Conducted**

Appendix I3-R – Shake Table Test Protocol, Records of Damage and Table Acceleration - 1/3rd scale Model (Type Design 3 - Repaired)

Type 3, One Third, Shake Table Test Protocols (retest after repair) [28-11-2018]			
Time History	**%age**	**Observations**	**Remarks**
EQ1	**F1/ Pulse Test**		
	Self Check 1	Mortar spalling, separation of lintel and eave band from masonry (Wall W3), cracking to inplane wall	
	F2/ Pulse Test		
	5	NC	
	10	No further damage	
	20	NC	
	30	No further damage other than sliding of lintel band (Wall W3)	
	40	Sliding of linel band, small diagonal crack in in-plane wall	
	50	Sliding of linel band, small diagonal crack in in-plane wall, further progression of earlier cracks	
	F3/ Pulse Test		
	60	Sliding of linel band, small diagonal crack in in-plane wall, further progression of earlier cracks/ damages	
	70	Sliding of linel band, small diagonal crack in in-plane wall, further progression of earlier cracks/ damages	
	80	Sliding of linel band, small diagonal crack in in-plane wall, further progression of earlier cracks/ damages	
	90	Sliding of linel band, small diagonal crack in in-plane wall, further progression of earlier cracks/ damages, minor crack at junction of walls at corners	
	100	No further extenstion of damage	
	F4/ Pulse Test		
EQ2	Self Check 2	Minor crusing of bricks, extenstion of earlier damages	
	60	Extenstion of earlier damages, but no stability of walls or any other components	
	F5/ Pulse Test		
	70	Extenstion of earlier damages, but no stability of walls or any other components	
	80	Extenstion of earlier damages, but no stability of walls or any other components	
	F6/ Pulse Test		
	90	Extenstion of earlier damages, but no stability of walls or any other components, rocking of OOP walls, spalling and falling of broken bricks in small chunk	
	F7/ Pulse Test		
	100	Extenstion of earlier damages, but no stability of walls or any other components, rocking of OOP walls, spalling and falling of broken bricks in small chunk	
	F8/ Pulse Test		
KIRT_EW	Self Check 3		
	F9/ Pulse test		
	100	No further new damage, extension of earlier damages	

Appendix I3-RL – Shake Table Test Protocol, Records of Damage and Table Acceleration - 1/3rd scale Model (Type Design 3 – Repaired – Longitudinal Direction)

Type 3, One Third, Shake Table Test Protocols, Direction of shaking: Longitudinal (retest after testing of repaired model in transverse direction) [29-11-2018]			
Time History	**%age**	**Observations**	**Remarks**
EQ1	**F1/ Pulse Test**		
	Self Check 1		
	F2/ Pulse Test		
	5		
	10		
	20		
	30		
	40		
	50		
	F3/ Pulse Test		
	60		
	70		
	80		
	90		
	100	Rocking of walls between bands (lintel and sill), expulsion and fall of bricks from OOP walls, sliding of wall along mortar layers, no damage to bands	
	F4/ Pulse Test		
EQ2	Self Check 2		
	60		
	F5/ Pulse Test		
	70		
	80		
	F6/ Pulse Test		
	90		
	F7/ Pulse Test		
	100	Extensive collapse of OOP walls between bands, toe crushing, severe damage to at wall junctions, severe damage to in-plane walls, no damage to bands, the vertical reinforcing elements encased in masonry appeared intact.	End of test
	F8/ Pulse Test		
KIRT_EW	Self Check 3		
	F9/ Pulse test		
	100		

OOP: Out of plane

Note: the model building was in extensively damaged state at the start of the test as the model was already been tested in the transverse direction after cosmetic repair (after testing in the longitudinal direction of virgin model).

Appendix I4 – Shake Table Test Protocol, Records of Damage and Table Acceleration - 1/3rd scale Model (Type Design 4)

Time History	%age	PGA (g)	Observations	Remarks	
	F1				**15-5-2018**
	Self Check 1	0.51	Clear horizontal cracks observed at sill and lintel level on all the walls.		
	F2				
EQ1	5	0.04	No further observations observed	**All Instruments in Place**	
	10	0.09	No further observations observed		
	20	0.12	No further observations observed		
	30	0.14	No further observations observed		
	40	0.21	No further observations observed		
	50	0.26	No further observations observed		
	F3				
	60	0.32	No further observations observed		
	70	0.39	No further observations observed		
	80	0.5	No further observations observed		
	90	0.57	No further observations observed		
	100	0.67	No further observations observed		
	F4				
	Self Check 2	1.06	1. Horizontal cracks at sill and lintel level aggravated. 2. Plaster falling has been observed mostly from the eaves level band. 3. Significant horizontal sliding at the eaves level was observed due to the significant thrust action of truss. Truss connection on W-3 has been detached. Gusset plate was teared.		
	F5				
EQ2	60	0.54	No further observations observed		
	70	0.71	No further observations observed		
	80	0.81	No further observations observed		
	F6				
	90	0.86	Spalling of Mortar Cover observed from Wall 1 and Wall 4		
	F7				
	100	0.89			
	F8		1. The existing cracks (horizontal) at the band level further aggravated a bit. 2. Rocking of buttress on the face loaded wall was observed.		
KIRT	Self Check 3	0.51	No further observations observed		
	100	1.15	1. Significant sliding observed at the sill, lintel and eaves band. 2. Out of plane wall was deforming to very large lateral displacement. 3. Significant spalling of plaster was observed on all walls.		
	Self Check 4	2.54	No further observations observed		
EQ3=EQ2 50%Containment removed from whole Model	60	0.72	No further observations observed	**Instruments removed except at A1 and D1 A1=6513 D1=SP-02 Ref: Acc= 6520**	**23-5-2018**
	70	0.71	No further observations observed		
	80	0.82	No further observations observed		
	90	1.14	Spalling of motar from stone joints observed		
	100	1.41	Rocking of Wall 1 buttress observed		
	Self Check 5	1.63	Spalling of loose stone from Wall 1 observed		
KIRT 2=KIRT	100%	1.62	No further observations observed		
KIRT NEW=KIRT 3 (scaled to 1.0g)	60	0.72	No further observations observed		**24-5-2018**
	70	0.71	No further observations observed		
	80	0.82	No further observations observed		
	90	1.14	No further observations observed		
	100	1.41	No further observations observed		

Appendix J1 – Photographic Images of Damage to 1/3rd Scale Model (Type Design 1)

Figure 1: Pre-test Picture

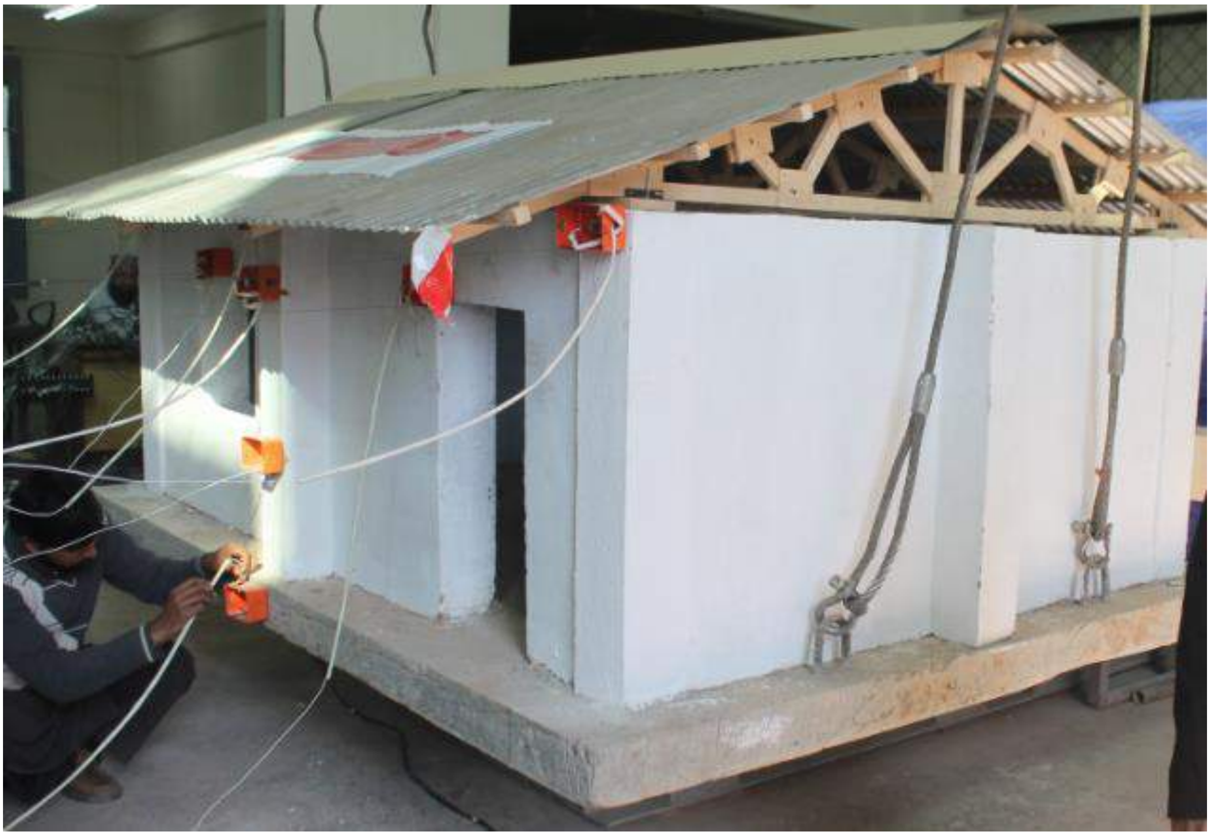


Figure 2: Pre-test Picture

Figure 3: Self Check

Figure 4: Self Check

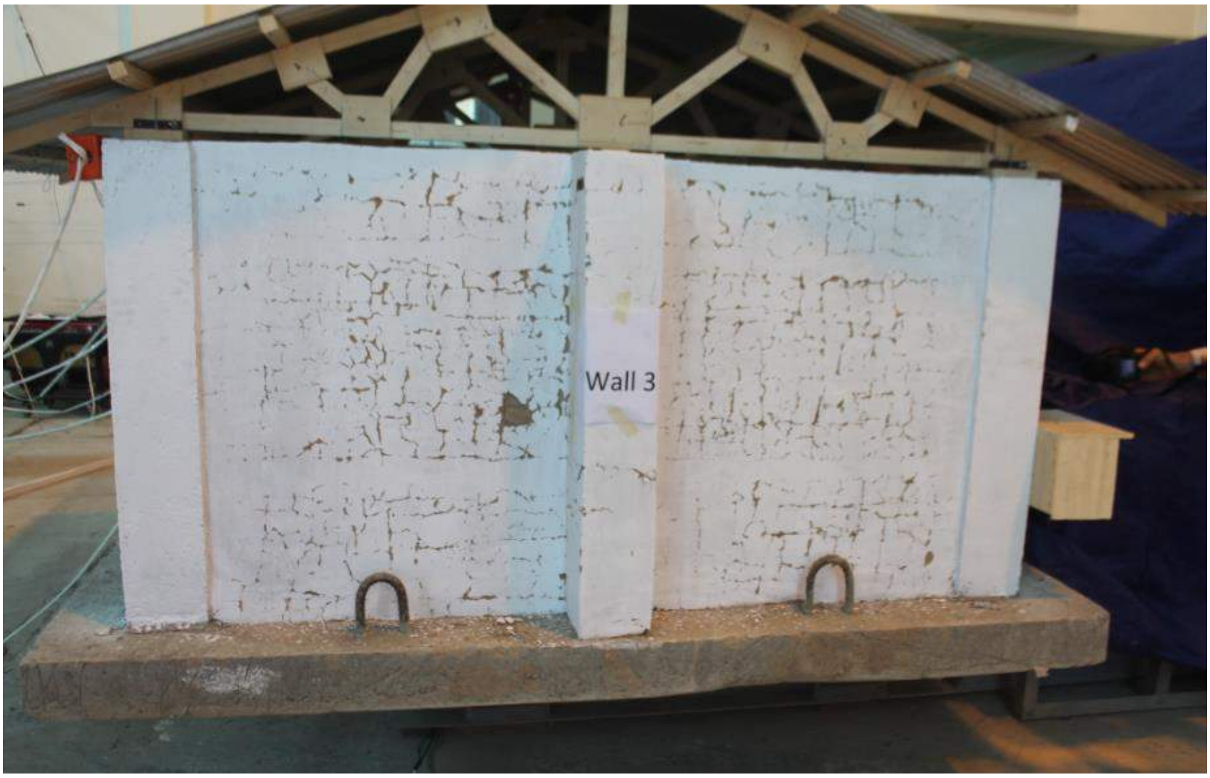


Figure 5: EQ2, 100%

Figure 6: EQ2, 100%

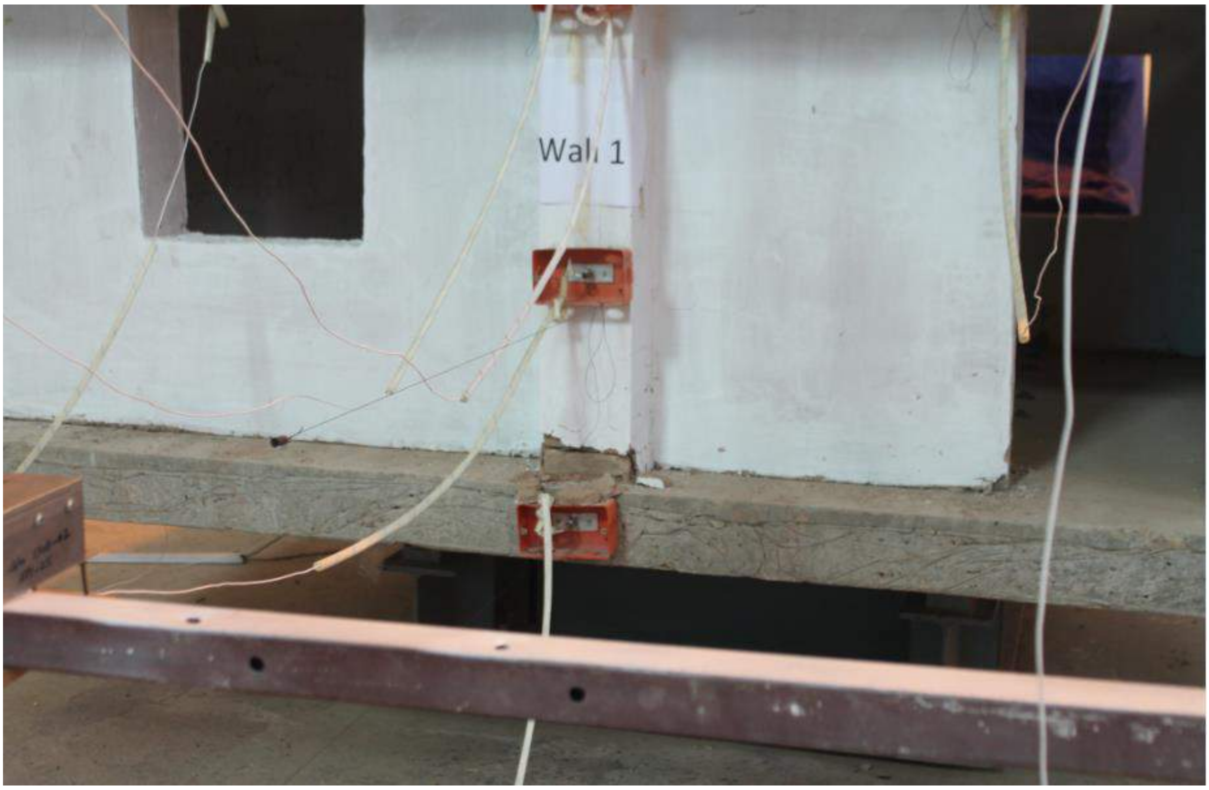


Figure 7: EQ2, 100%

Figure 8: EQ2, 100%

Figure 9: EQ3, 100%

Figure 10: EQ3, 100%

Figure 11: EQ3, 100%

Figure 12: EQ3, 100%

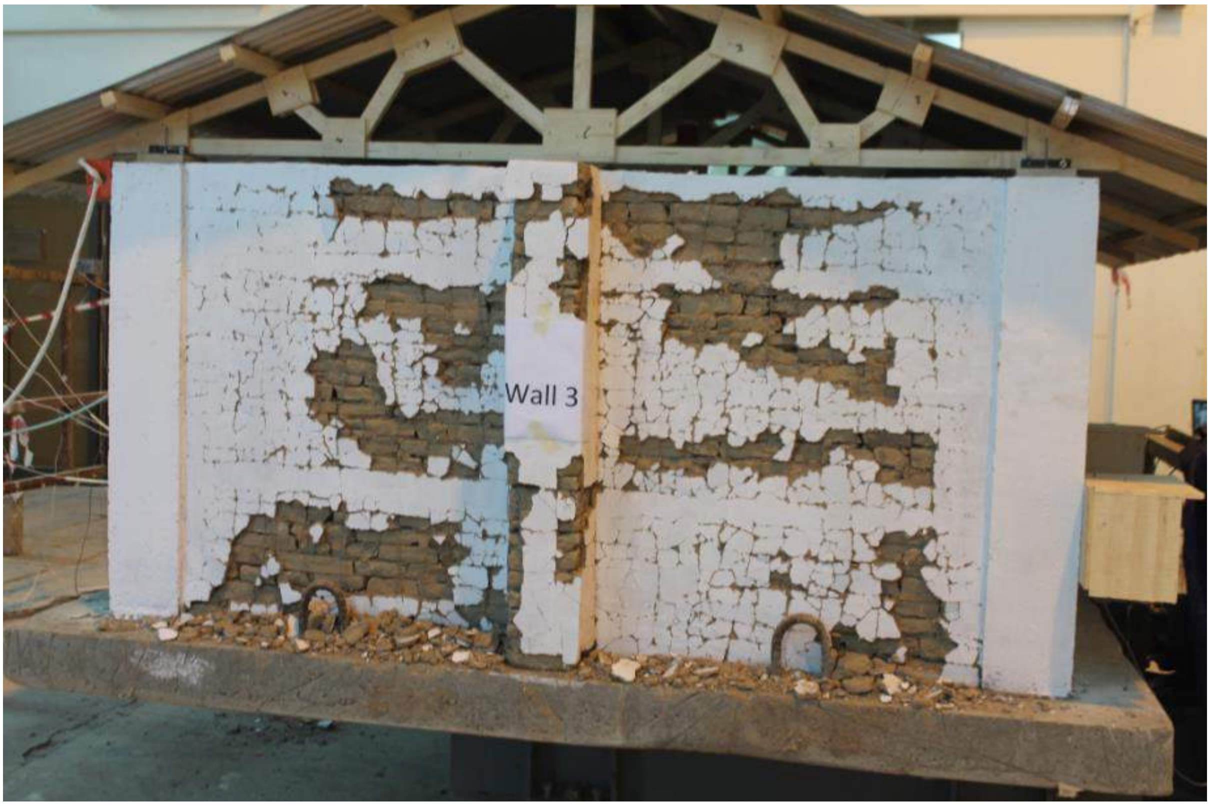


Figure 13: EQ4, 100%

Figure 14: EQ4, 100%

Figure 15: EQ4, 100%

Figure 16: EQ4, 100%

Figure 17: EQ5, 70% (After removal of Containment)

Figure 18: EQ5, 100% (After removal of Containment)

Appendix J2 – Photographic Images of Damage to 1/3rd Scale Model (Type Design 2)

Figure 1: Pre-test Picture

Figure 2: Pre-test Picture

Figure 3: EQ1, 100%

Figure 4: EQ1, 100%

Figure 5: EQ1, 100%

Figure 6: EQ1, 100%

Figure 7: EQ2, Self-Check 2

Figure 8: EQ2, Self-Check 2

Figure 9: EQ2, Self-Check 2

Figure 10: EQ2, Self-Check 2

Figure 11: EQ2, 70%

Figure 12: EQ2, 70%

Figure 13: EQ2, 70%

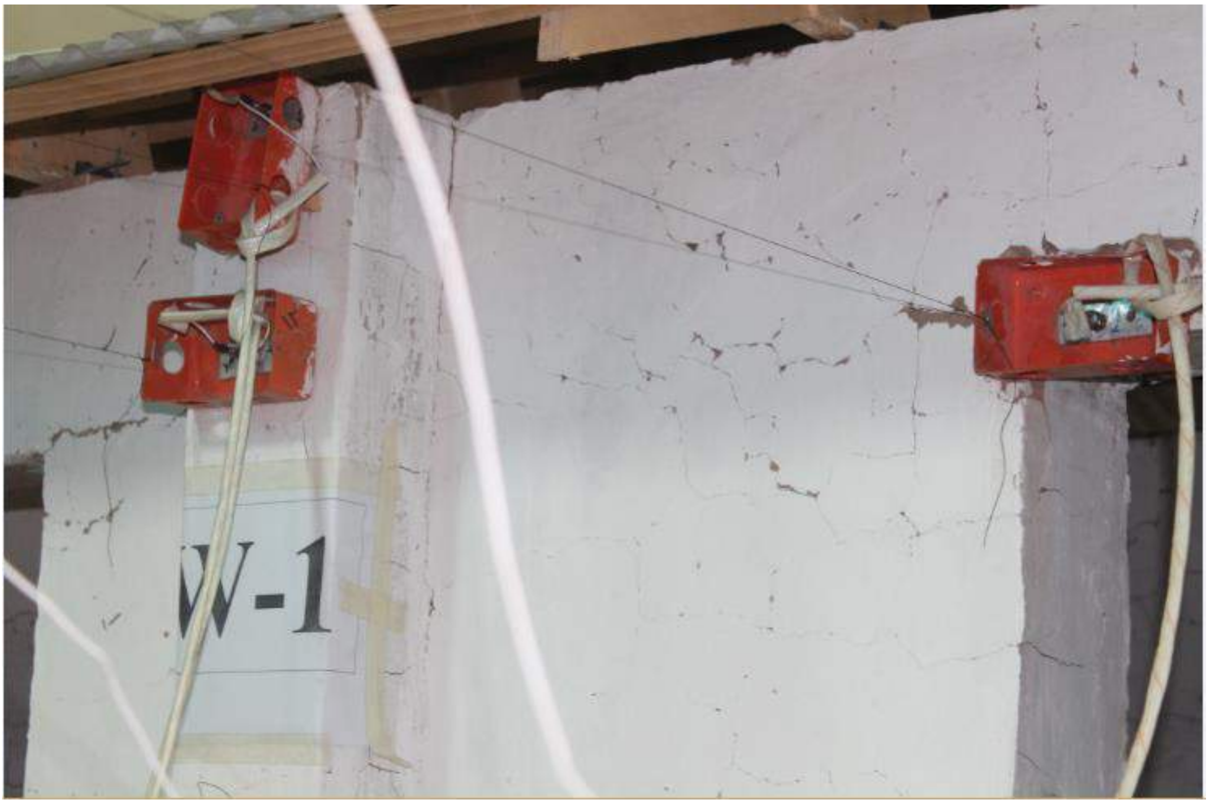


Figure 14: EQ2, 70%

Figure 15: EQ2, 100%

Figure 16: EQ2, 100%

Figure 17: EQ2, 100%

Figure 18: EQ2, 100%

Figure 19: EQ2, 100%

Figure 20: EQ2, 100%

Appendix J3 – Photographic Images of Damage to 1/3rd Scale Model (Type Design 3)

Figure 1: Pre-test Picture

Figure 2: Pre-test Picture

Figure 3: Self Check 1

Figure 4: Self Check 1

Figure 5: Self Check 2

Figure 6: Self Check 2

Figure 7: Self-Check 2

Figure 8: Self-Check 2

Figure 9: EQ2, 100%

Figure 10: EQ2, 100%

Figure 11: EQ2, 100%

Figure 12: EQ2, 100%

Figure 13: EQ2, 100%

Figure 14: EQ2, 100%

Appendix J4 – Photographic Images of Damage to 1/3rd Scale Model (Type Design 4)

Figure 1: EQ1, 100%

Figure 2:EQ1, 100%

Figure 3: EQ1, 100%

Figure 4:EQ1, 100%

Figure 5: EQ2, 100%

Figure 6:EQ2, 100%

Figure 7: EQ2, 100%

Figure 8; EQ2, 100%

Figure 9: KIRT, 100%

Figure 10: KIRT, 100%

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