SEISMIC PERFORMANCE OF REINFORCED CONCRETE WALL-SYSTEM WITH ELECTRO-WELDED MESH

Jenny Taira Higa* **Supervisor: Shunsuke SUGANO****
MEE08172 **Taiki SAITO*****

ABSTRACT

A new structural system consisting of reinforced concrete wall with electro-welded mesh is being used for the buildings construction in Peru. These walls have small thickness. The Peruvian standards for this wall –system were published in 2004 in order to restrict the use of the electro-welded mesh as main reinforcement. However many buildings have been built before that and electro-welded mesh was used as reinforcement for whole building.

In order to evaluate the behavior of this system, the test results of 7 isolated walls and 1-story wall-system house were used. This test results have been compared with analytical results in order to find out an adequate way for the analysis of this wall-system. In the isolated walls analysis, the cracking strength and ultimate strength were calculated to apply a tri-linear model to be used in the degrading tri-linear hysteresis model to compare it with the hysteretic curve of the isolated walls. The isolated wall analysis was applied in the analysis of 1-story wall-system house to evaluate its behavior and compare it with test results. In order to apply the proposed evaluation methods, a 2-story house wall system was analyzed to evaluate the seismic response by the displacement method using the degrading tri-linear hysteresis model.

It is expected to use this analysis to evaluate the behavior of existing and new buildings using the reinforced concrete wall-system with electro-welded-mesh.

Keywords: hysteresis model, strength, behavior, seismic performance.

1. INTRODUCTION

Since 2000, many buildings in Peru have been built with a new structural system consisting of reinforced concrete with ductile steel bars at the ends and electro-welded mesh in the middle part to support gravity and lateral loads. The minimum thickness for these walls is 10 cm and reinforcement is arranged in one line. In October 2004, the addendum for the standard of building design with these walls was published in order to standardize the criteria for the analysis and design of these buildings. This standard restricts the use of electro-welded mesh as main reinforcement for the building construction due to its low ductility compared with ductile steel (See Figure 1). However, many buildings were built before the publication of the above standards; the electro-welded mesh has been used as main reinforcement for whole building for the sake of reducing cost.

According to the standard, the electro-welded mesh is allowed as reinforcement in buildings up to 3 stories. In case of higher-story buildings, electro-welded mesh is prohibited for the lower one third of the total high of the building of 4 stories or higher. The maximum number of story is 7. In case of higher buildings the wall thickness should be greater than 15

* Japan - Peru Center for Earthquake Engineering Research and Disaster Mitigation (CISMID), Peru.
** Visiting Research Fellow, International Institute of Seismology and Earthquake Engineering, Building Research Institute, Japan.
*** International Institute of Seismology and Earthquake Engineering, Building Research Institute, Japan.

cm six stories lower from the top and below that story, to allow the confinement at the ends of the walls. The maximum relative displacement for each story divided by its height should not exceed 0.005.

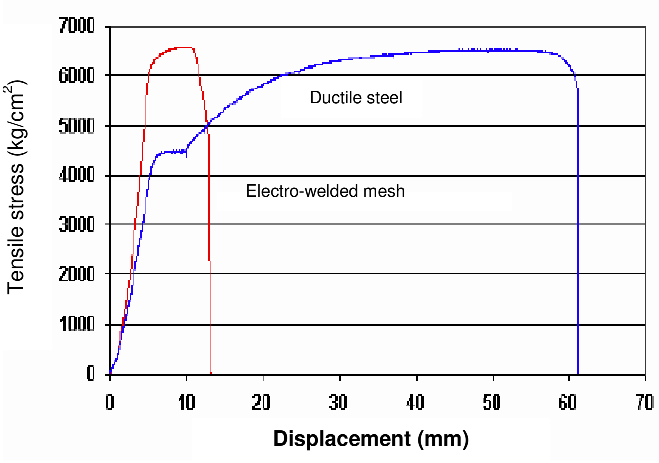


Figure 1. Tensile tests for ductile steel and electro-welded mesh

The advantages of this system are its rapid process of construction since electro-welded mesh is pre-fabricated and concrete is pre-mixed. These factors reduce the cost, time and labor in the construction. The high walls density makes the structure becomes rigid. The main disadvantage is its low ductility due to concrete and mesh are not ductile materials.

2. OBJECTIVES

The objectives of this thesis are to evaluate the behavior (load-displacement relationship) of isolated walls obtained from the laboratory test using the "tri-linear model". Also, to evaluate the cyclic behavior (cyclic load-displacement relationship) of a one-story wall-system house obtained from the laboratory test using the "degrading tri-linear hysteresis model". In order to achieve this objective, the analysis of 7 isolated walls and 1-story wall-system house tested in laboratory were carried out to compare the hysteretic curve from test and analysis. This analysis was applied to evaluate the seismic response of a 2-story wall-system by the displacement method.

The analysis is intended to be applied in order to evaluate the performance in new and existing buildings. In case of new buildings, the use of the electro-welded mesh is restricted. For existing buildings built before the standard publication, this evaluation can be used to know whether the building requires retrofitting.

3. ANALYSIS OF ISOLATED WALLS

In the analysis of isolated walls, 7 full scale isolated walls tested in the Laboratory of Structure in CISMID in 2004 were used. The parameters were the kind of electro-welded mesh and dowel to join wall and foundation.

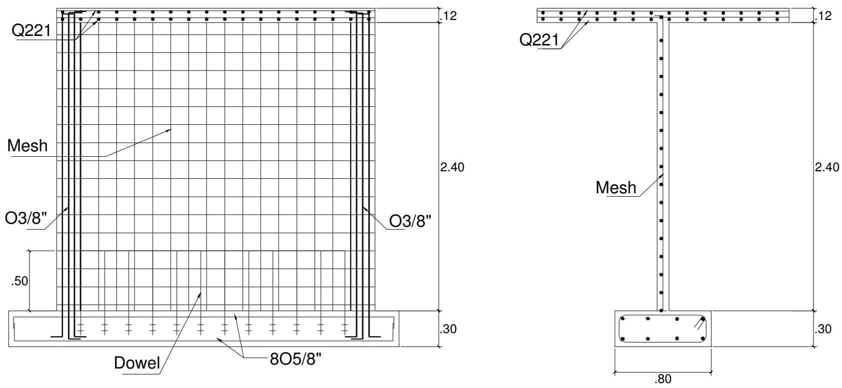


Figure 2. Characteristics of isolated wall

Table 1. Isolated wall reinforcement

Specimen	Reinforcement	Dowel
MQE188EP-01	QE188	QE84/188
MQE188EP-02	QE188	QE84/188
MQE188EP-03	QE188	ϕ3/8@25
MQE257EP-01	QE257	QE84/257
MQE257EP-02	QE257	QE84/257
MQE257EP-03	QE257	ϕ3/8@25
MFIEN3EP-01	ϕ3/8”@25	ϕ3/8@25

Table 2. Characteristics of reinforcement

Mesh	Diameter (mm)	Spacing (mm)	Density (mm^2/m)
QE-188	6.00	150	188
QE-257	7.00	150	257
QE-84	4.00	150	84
ϕ3/8”	9.5	250	284

For each isolated wall, the skeleton curve was plotted from the hysteretic curve of the tested wall. These skeleton curves were used in the comparison with analytical results explained below.

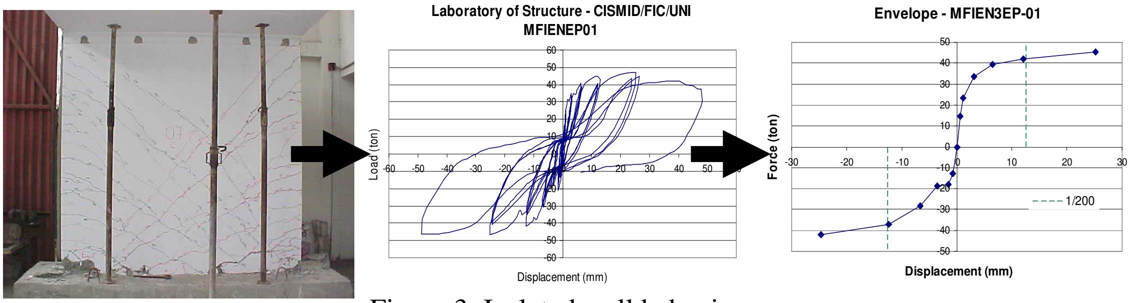
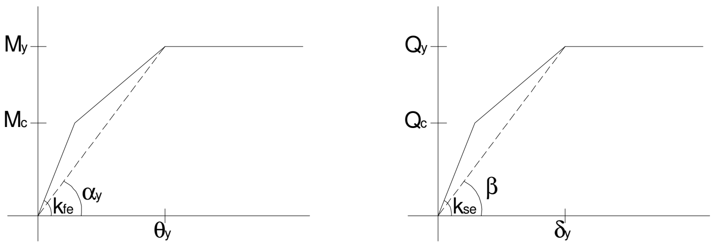


Figure 3. Isolated wall behavior



Flexural model

Shear model

Figure 4. Tri-linear model

For the tri-linear model, the cracking and ultimate strength were calculated in flexure and shear. This was made to know how the behavior of isolated walls is. According to the results, the isolated walls have flexural behavior (See Figure 4). The equations for the calculation of tri-linear model were shown below:

- Flexural cracking strength:

$$M_c = 0.56\sqrt{\sigma_B} Z_e + \frac{ND}{6} \tag{1}$$

- Ultimate flexural strengtn:

$$M_u = a_t \sigma_y l_w + 0.5 a_w \sigma_{wy} l_w + 0.5 N l_w \tag{2}$$

- Stiffness reduction at flexural yielding:

$$\alpha_y = \left(-0.0836 + 0.159\frac{a}{D} + 0.169\eta_0 \right)\left(\frac{d}{D}\right)^2, \text{ a/d} < 2 \tag{3}$$

- Shear cracking strength:

$$V_c = \frac{\tau_{scr} t_w l_w}{x_w} \tag{4}$$

- Ultimate shear strength:

$$Q_{wsu} = \left\{ \frac{0.068 p_{te}^{0.23}(18 + F_c)}{\sqrt{\frac{M}{QD} + 0.12}} + 0.85\sqrt{p_{wh}\sigma_{wh}} + 0.1\sigma_0 \right\} t_e \cdot j \tag{5}$$

- Stiffness reduction at ultimate shear strength:

$$\beta_u = \frac{0.46 p_w \sigma_y}{F_c} + 0.14 \qquad (6)$$

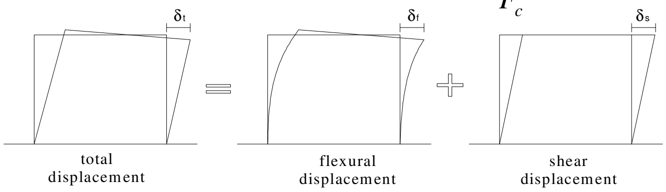


Figure 5. Total displacement

In order to obtain a better approximation in the flexural model, the displacements in shear were added to the displacements in flexure.

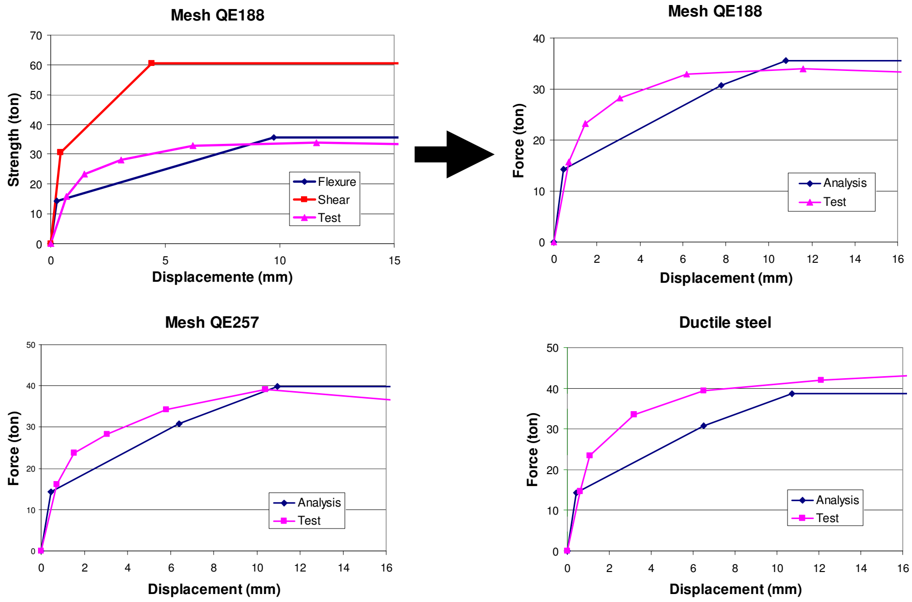


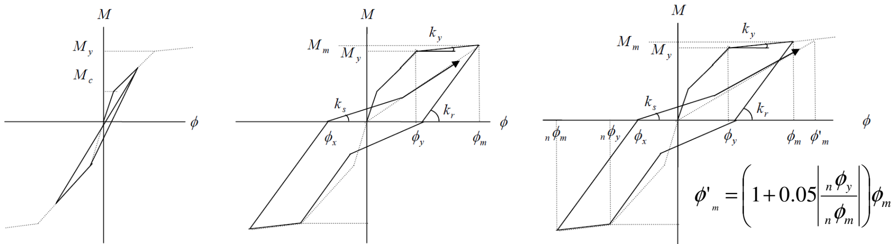
Figure 6. Flexural and shear tri-linear model and total displacement.

The equations used for the calculation of the cracking and ultimate strengths can be used to describe the behavior for this kind of walls.

4. ANALYSIS OF 1-STORY WALL-SYSTEM HOUSE

In 2004, 1-story house was tested in the Laboratory of structures of CISMID, at the same time for walls. The house walls have the same characteristics of the isolated walls. In the reinforcement was used mesh QE188. According to the behavior, the maximum load was 88 ton for a displacement of 11 mm.

The degrading tri-linear hysteresis model was used in the comparison with the behavior from the test. This hysteresis model considers the (a) yielding stiffness, (b) stiffness degradation, (c) slip stiffness and (d) strength degradation.



$$\phi'_m = \left(1 + 0.05\left|\frac{{}_n\phi_y}{{}_n\phi_m}\right|\right)\phi_m$$

(d)

$$k_y = -0.01\left(\frac{M_y}{\phi_y}\right) \qquad k_r = \left(\frac{M_y}{\phi_y}\right)\left|\frac{\phi_y}{\phi_m}\right|^{0.05} \qquad k_s = \left(\frac{M_m}{\phi_m - \phi_x}\right)\left|\frac{\phi_y}{\phi_m}\right|^{0.1}$$

(a) (b) (c)

Figure 7. Degrading tri-linear hysteresis model

For the analysis, the house walls were replaced by shear spring devices with the properties of walls by using the hysteresis model based on degrading tri-linear model. The same calculation for the analysis of isolated walls was made for the house walls. In the analysis was used Stera3D computer program made by Dr. Saito.

Comparison in Skeleton Curve	Test	Analysis
Cracking strength (ton)	30	27.4
Ultimate strength (ton)	73.8	73.2
Elastic stiffness (ton/mm)	45.9	72.1

According to the comparison, the behavior calculated by using the hysteresis model for flexure shows a good approximation compared with test results. For this reason, hysteresis model for shear was not taken into account. The values for cracking and ultimate strength has a small variation compared with the test results. In case of elastic stiffness, the variation is around 50%. This can occur due to shrinkage, small fissures or cavities in the concrete walls. However, this variation is acceptable in the analysis and it can be considered as good result.

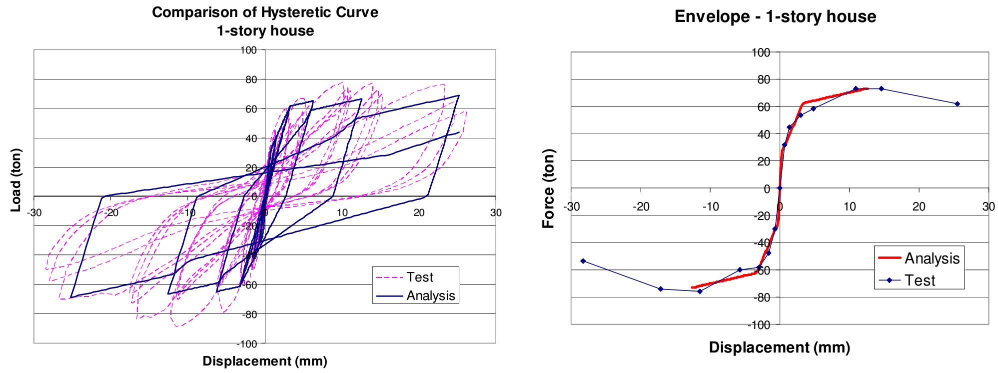


Figure 8. Comparison between test and analytical results

5. SEISMIC PERFORMANCE OF 2-STORY WALL-SYSTEM HOUSE

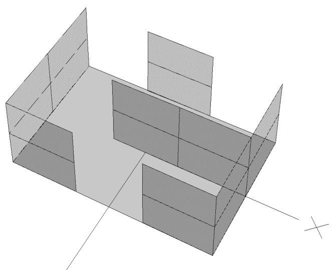


Figure 9. Analytical model

In order to evaluate the seismic response of a 2-story house, the displacement method using the degrading tri-linear hysteresis model was used. For the model, the 1-story house was extended to 2 stories.

The capacity spectrum was calculated from the shear force-displacement relationship by using the equation to calculate the spectral acceleration and spectral displacement. The demand spectrums was calculated from the response spectrums of Peruvian seismic code, Japanese building standard and the earthquake occurred in Peru in October 1966. This earthquake had the maximum acceleration registered in Peru. The maximum acceleration was around 270 gal.

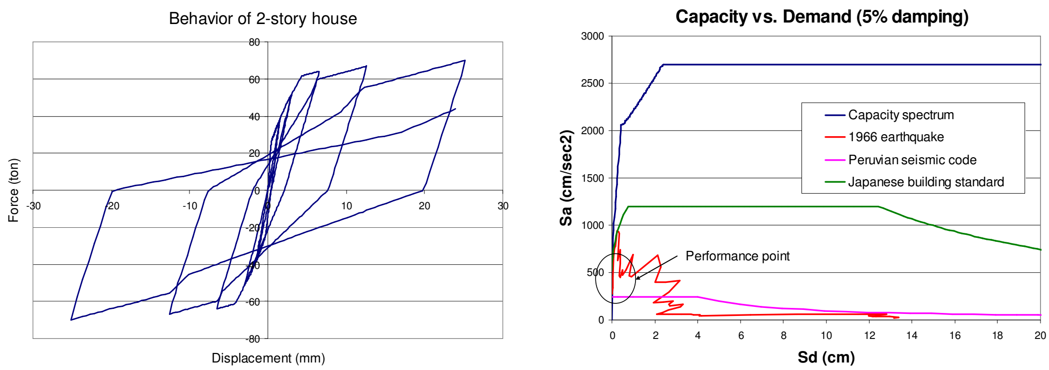


Figure 10. 2-story house behavior and performance point

The demand spectrums were calculated for 5% damping, this means for elastic range. Despite this, in all cases the displacement in the performance point is very small. The structure remains in the elastic range in the capacity spectrum, therefore the structure should not suffer damage. The total strength of the walls is 2.3 times larger than the weight of the structure; therefore the structure becomes very rigid and the spectral acceleration in the capacity spectrum is high compared with demand spectrum.

6. CONCLUSIONS

- The load-displacement relationship of isolated walls obtained from the laboratory test was well predicted by the tri-linear model for flexural and shear displacements. The behavior of isolated walls is by flexure. In order to improve the analytical results, the shear displacements were added to flexural displacements. The difference between analytical and test results for strength varies between 2% and 8%.
- The cyclic load-displacement relationship of a one-story wall-system house obtained from the laboratory test was well predicted by the degrading tri-linear hysteresis model. The ultimate strength calculated in the analysis is very close to the maximum load in the tests. This variation can be reduced taking into account a modeling for shear in the analysis. Despite this, the modeling for flexure can be used to predict the behavior for a structure with good results.
- The seismic response of the 2-story wall-system house was evaluated based on displacement method using the degrading tri-linear hysteresis model. This method is proposed for the evaluation of the performance in buildings that use this structural system.
- The hysteresis models proposed in this study can be applied to existing buildings and buildings in new construction using the reinforced concrete wall-system with electro-welded mesh to evaluate their seismic behavior.

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