STRENGTHENING OF A 1902'S L-SHAPED THREE STOREY UNREINFORCED MASONRY BUILDING IN INDONESIA

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SUMMARY

A beautiful L-shaped three storey unreinforced masonry (URM) building is located in the city of Semarang, Central Java, Indonesia. The building was constructed in 1902 as the main office of the Dutch Railway Company and later it was utilised as the Indonesian army headquarter. Currently a plan is being made to function the building as a five-star hotel by retaining the existing structure and architectural features as far as possible. To anticipate the likely seismic hazard in the region, a series of in-elastic time history analyses were carried out to investigate the in-plane performance of the URM walls. Analyses results show that the URM walls perform well when subjected to 20-year return period ground excitations based on the Indonesian Seismic Code. However, these walls need to be strengthened to withstand a 200-year return period earthquake which likely to occur in the region. Based on the analytical studies as well as economic considerations, it is recommended to apply a major strengthening scheme in form of 50 mm concrete topping with some reinforcement on the entire existing floor slabs. Shotcrete overlays are also need to be applied on both sides of the URM walls in order to enhance their shear strength.

INTRODUCTION

“Building of Thousand Doors” is the popular name of a nice looking L-shaped three storey unreinforced masonrry (URM) building located at the centre of the city of Semarang, Central Java, Indonesia. It was constructed in 1902 for the Dutch Railway Company as their Indonesia main office. Later the building was utilised as the Indonesian army headquarter for some years.

Currently an investor is attracted to function this beautiful old building as a five star hotel. In order to be able to preserve the building for the years to come, a thorough evaluation need to be carried out in order to investigate the performance of the URM walls when they are subjected to the maximum credible earthquake which might occur in the region based on the current Indonesian seismic code.

Unfortunately in Indonesia, there is still no guidance for assessing the seismic performance of such buildings as well as strengthening them. The recent renovation projects of old buildings in Indonesia only involve exterior cosmetics and/or non-structural modifications such as replacing floor material, roof, etc without studying their structural performance, in particular against the lateral seismic forces.

This paper presents analytical studies conducted in order to evaluate the seismic performance of the URM building mentioned above, before and after the strengthening scheme being applied.

DETAIL DESCRIPTION OF THE BUILDING

The Building of Thousand Doors was constructed in 1902 by the Dutch government and started to be used as the state railway main office in 1907. Since the Japanese occupation (1942-1945) the building was used as an army

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headquarter until the 1980's. In 1996 an Indonesian private investor in conjunction with the operator of the Raffles Hotel, Singapore, became interested to alter the function of the building into a five-star hotel, while still preserving the existing structure and architectural features as far as possible.

The building consists of 2 main floors and one attic-room directly under the steel roof truss of double-angles. The heights of the first floor, second floor and the attic are 5.440 m, 5.096 m and 7.000 m respectively. The L-shaped floor plan as shown in Fig. 01 has lengths of 73.20 m at its longest leg and 52.00 m at its shortest leg while the building's width is 23.10 m. The area per floor is thus around 2400 m².

The grand-staircase is found at the main entrance area, with a wide floor opening, connecting the first and second floors. The URM walls are continuous from the ground floor straight up to the attic with a consistent thickness, i.e. 30 cm, 42 cm, 50 cm and 65 cm and placed crosswise. Conform to its name, almost in every wall of the building door openings can be found. These openings provide natural light and also cause the surrounding URM walls to function as piers.

The floor slabs consist of bricks stacked in an arch resting along secondary steel I-beams, 60-100 cm centre to centre. A layer of lime mortar is found on top of the bricks. The total thickness of the slabs near the support is around 30 cm. Floor finishing on the first and second floor is ceramic tiles while the attic room is finished with lime mortar.

The foundation of the building is strip-footing made of stones filled with lime mortar to a height of 100 cm - 150 cm and a width of 150 cm. The ground floor consists of masonry arches spanning between secondary steel I-beams which form the space underneath to only a crawling-height. During the revolution, the space was used as a shelter. The soil underneath consists of clay layers where the hard soil layer is found at a depth of around 40 metres.

The roof frames, which were made of double angle steel trusses with a span of around 20 metres, are simply supported directly on top of the URM walls with a distance of 3 metres to each other.

MATERIAL CHARACTERISTICS

The masonry units, popularly known in Indonesia as red masonry, are made of clay with or without a mixture of other substances and burned at a sufficiently high temperature so that they will not crumble when soaked in water. The common process of production as currently known is a mixture of excavated soil, water, with or without other substances, while moulding may be done manually with a wooden mould or a pressing machine. As a result of the relatively simple production process and the lack of strict supervision it is difficult to obtain masonry of an adequately homogeneous quality.

Masonry unit samples from the site show an average dimension of 256 mm in length, 121 mm in width and 53 mm in thickness. The specific gravity of the URM unit was found 1850 kg/m3. Results of compressive strength tests which were carried out in accordance with the Indonesian Standards are quite variable, i.e. from 3.4 MPa to 12.5 MPa. To obtain an average representative value, one test result of 12.5 MPa was excluded from the obtained data. Thus the evaluation was based only on 29 samples and the average compressive strength, f'm was found 6.5 MPa. The young modulus of 750 f'm [Paulay & Priestley, 1992] was taken giving a value of 4875 N/mm2. The ultimate strain was considered to be 0,004.

STRUCTURAL ANALYSES

A series of structural analyses using a commonly used computer program ETABS v.6.10 [Habibullah, 1995], were carried out as a preliminary study to evaluate the out of plane as well as the in plane performance of the building's URM-walls under the combination of gravity and seismic lateral loads. For this purpose all URM walls were modelled as panel elements and the horizontal floor slabs were considered as rigid floor diaphragms. The strip-footing foundation was idealised as a winkler spring model.

Results [Wijanto & Takim, 1999] show that under the strong and severe earthquakes almost all URM walls depict satisfactory out of plane performance. However, in their in-plane direction it was found that most of the developed forces exceed the elastic limit strengths of the walls. Therefore it was considered necessary to carry out in-elastic time history analyses to further investigate the in-plane seismic performance of these URM walls.

For conducting the in-elastic time history analyses, the computer program Ruaumoko [Carr, 1998] was used. Since this program can only carry out two dimensional structural analyses, the existing building is modelled as a one-degree of freedom spring model where the lateral masses and stiffness are lumped in the joints as shown in Fig. 02 It is assumed that each wall can only provide strength and stiffness in the in-plane direction, whereas the strength and stiffness in the out of plane direction is ignored. The spring model is assumed to have a non-linear hysteresis behaviour, as shown in Fig. 03, which is very typical for representing the response of rocking wall structures.

The floors of the building are modelled as standard elastic beam members with two kinds of assumption. First it assumed that the beam members have pin joints at each end, which represent the existing condition of the floor slabs. As they are not monolithic with the wall, the floors have practically no flexural stiffness although they have stiffness in compression and tension. Second it is presumed that the beam members have fixed joints at each end representing the floor slabs which are fixed connected to the URM walls. This condition is reached after the strengthening scheme is applied. In this case the floor slabs have flexural stiffness as well as axial stiffness.

The N-S component of El Centro 1940 earthquake record was applied along the short side of the building (Y-direction) whereas its E-W component was applied along the long side of the building (X-direction). Three scale factors of 20%, 50% and 75% were used to represent the major (20-year return period), strong (Indonesia draft code 1999) and severe (200 year return period) ground excitations in the region. Figure 04, shows the comparison between these three scaled earthquake's acceleration response spectra and the acceleration response spectrum of the Indonesian seismic code for 20 and 200 year return period.

As the result of the analyses it was found that the lateral displacements in the Y-direction of Nodes 1, 13, 19 and 69 (see the computer modelling in Fig. 2), before and after the strengthening scheme was applied, are as tabulated in Table 1 and also shown in Fig. 5. Node 1 represents the far-end URM walls while Nodes 13 and 19 represent URM walls located in the middle of the relatively more flexible wing (in the Y-direction). Node 69 represents URM walls in the far-end of the relatively stiffer wing (in the Y-direction). The maximum bending moments and shear forces occur within the floor diaphragm, after the strengthening scheme was applied are as shown in Fig. 6.

THE PROPOSED STRENGTHENING SCHEME

The main purpose of applying a strengthening scheme is to enhance the seismic performance of the building. However, the selected scheme shall not only be effective, but also practical and economical. After considering the results of the in-elastic time history analyses, it is proposed to apply a concrete topping of 50 mm with D16 flexural reinforcement as shown in Fig. 07. The reinforcement is also need to be penetrated through the URM walls to create rigid connection between the floor diaphragms and the URM walls and thus a rigid floor diaphragm.

As demonstrated in Table 1 and also shown in Fig. 5, it was found from the analyses that at the existing condition Nodes 13 and 19 (see Fig. 2) which represent the URM walls located in the middle of the more flexible wing (in the Y-direction) have much larger lateral displacements compared to the lateral displacements of Nodes 1 and 69 which represent the far-end URM walls of the more flexible and stiffer wings (in the Y-direction) respectively.

After the application of the strengthening scheme in form of 50 mm concrete topping, it was found that due strong and severe earthquakes these nodes experienced more uniform lateral displacements than before the concrete topping was applied. A much smaller discrepancy of lateral displacements between walls will reduce the degree of damage during strong and severe earthquakes.

It was also found that due to the 20-year return period earthquakes the URM walls are still in their elastic states and therefore the lateral displacement of Node 1 which represent the far-end URM walls in the more flexible wing (in the Y-direction) is much larger than the lateral displacement of Node 69 which represent the far-end URM walls in the stiffer wing (in the Y-direction)

The above selected scheme should be applied together with the application of 30 – 50 mm shotcrete overlays on both sides of some URM walls, particularly URM walls in the area of the grand staircase. Due to the 20 year return period earthquake none of the shear demand exceeds the shear capacity of the URM walls. However, due to 200 year return period ground excitation the shear capacity of the near-end URM walls of both wings of the building, i.e. in the area of grand staircase, is almost exceeded. The application of shotcrete overlays on both sides of these walls will increase their shear capacity.

All other URM walls need also to be inspected thoroughly and if necessary to be repaired to ensure that there are no more cracks, cover peelings etc. Beside that, the strip footing foundation which consists of well arranged boulders with lime mortar need also to be inspected carefully. And if necessary, some repairs need to be conducted by applying shotcrete overlays on both sides of this foundation. Parts of the foundation which are experienced cracks and /or have holes need to be grouted to ensure the integrity of the whole foundation system.

CONCLUSIONS

A thorough investigation was conducted using a series of time history analyses as reported in this paper to assess the seismic in-plane performance of an attractive L-shaped three storey building located in Semarang, Central Java, Indonesia and constructed in 1902.

A strengthening scheme for the L-shape three storey URM building is proposed based on results of the in-elastic time history analyses. These analyses were carried out using scaled N-S and E-W components of El Centro 1940 earthquake to represent the major, strong and severe ground excitations in the region. The proposed scheme was in form of 50 mm concrete topping with some reinforcements cast on top of the floor slabs, shotcrete overlays applied on both sides of the strip foundation and the URM walls, especially the ones in the grand stairs area. Cracked URM walls must also be repaired by grouting the caves.

The 50 mm concrete topping with some reinforcement may forms rigid floor diaphragms which distributes the seismic inertia forces more uniformly among the URM walls and therefore it was found that the lateral displacements of most URM walls in the Y-direction were reduced and also tend to be uniform. This phenomenon will definitely reduce the likely damage on the walls due to the non-uniform lateral displacements among the URM walls. The total area of the reinforcements was determined by the maximum bending moments and shear forces experienced by the floor diaphragms, especially in the area of connections between floors and walls.

The shotcrete overlays were also applied, as part of the strengthening scheme, on both sides of the URM walls especially the ones close to the grand stairs area. These overlays would enhance the shear capacity of these walls.

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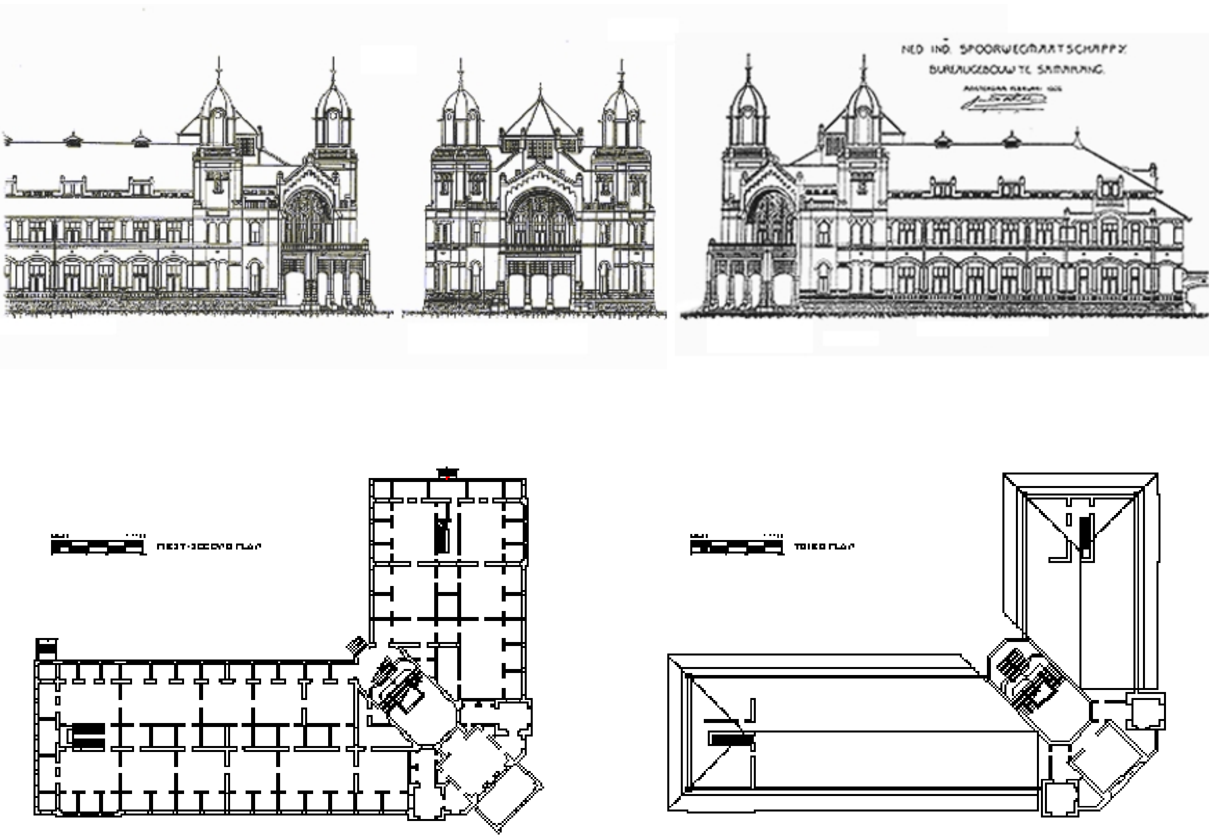

Fig. 1 : Building View And Floor Plans

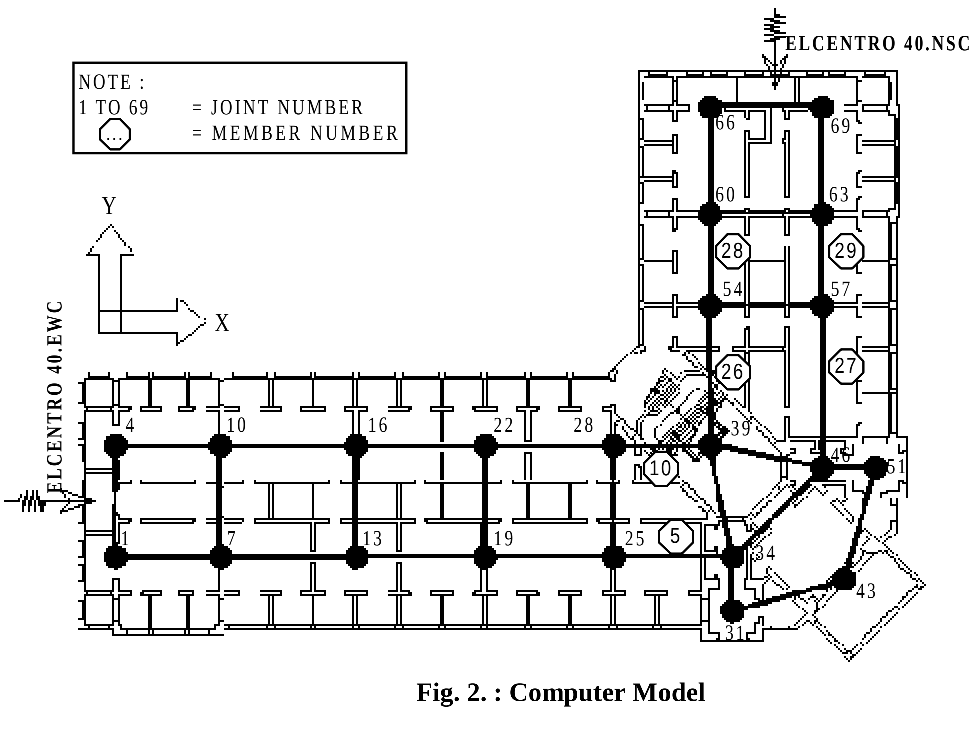

Fig. 2. : Computer Model

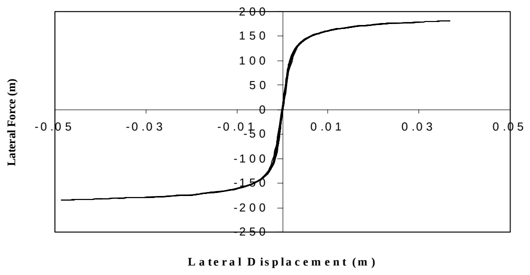

Fig. 3 : Hysteresis Model of URM Walls

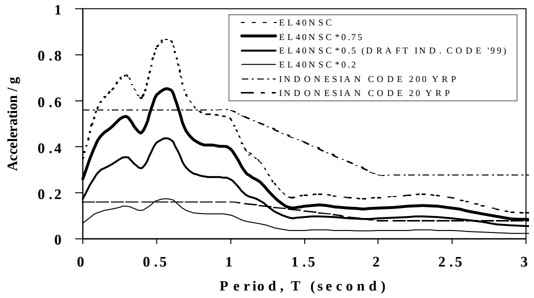

Fig. 4. : Elastic Reponse Spectra for The Earthquake Records as Input Ground Motion in The Analyses

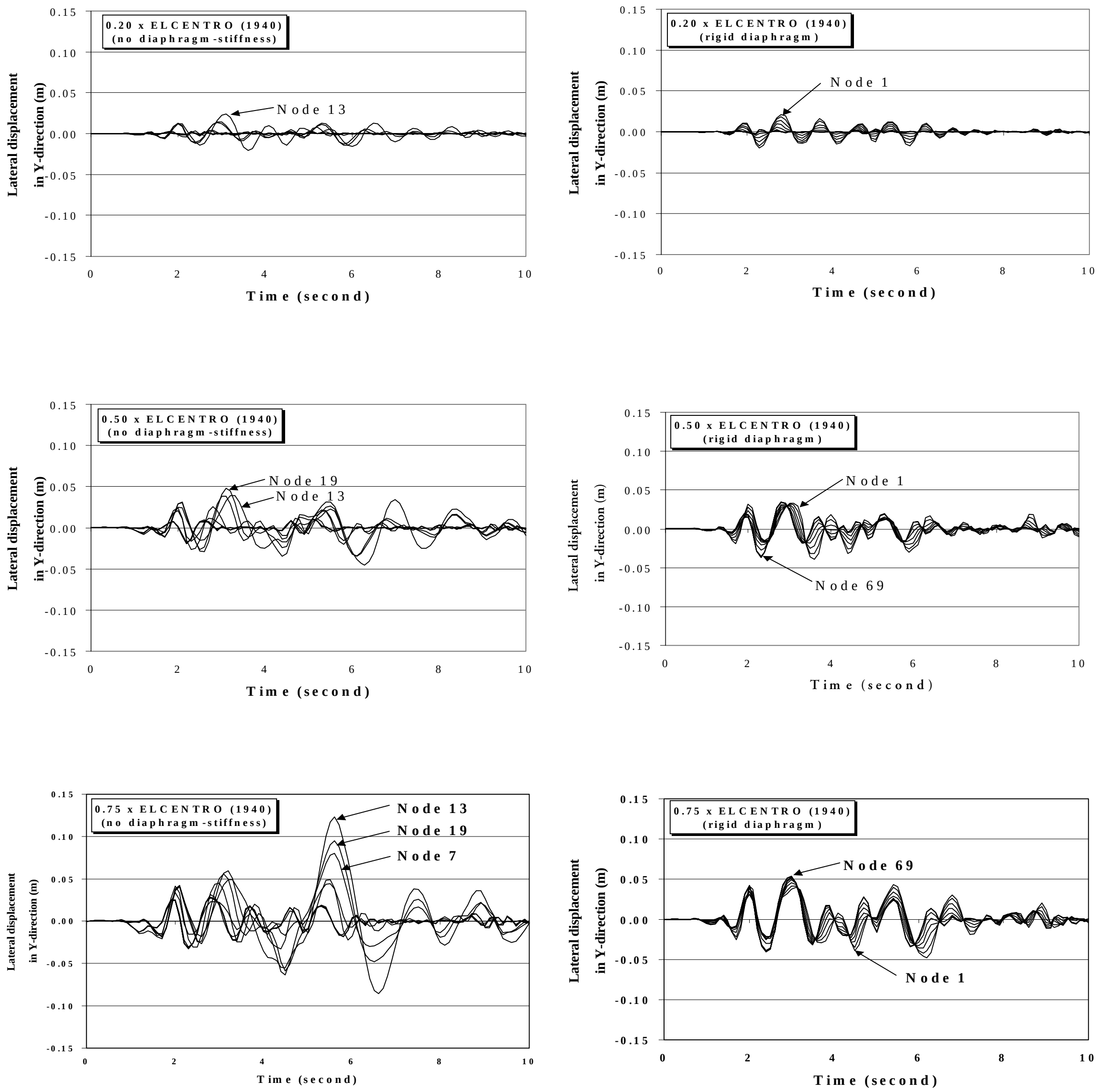

Fig. 5. : Time-History Plots of Lateral Displacement for Two Type of Diaphragm Stiffness With Different Scale Factors of El Centro Ground Acceleration

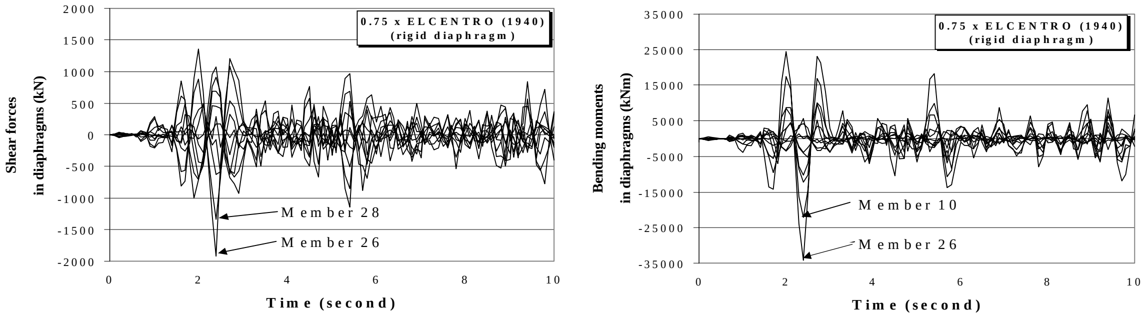

Fig. 6 : Maximum Bending Moments And Shear Forces in Rigid Diaphragm With Concrete Topping

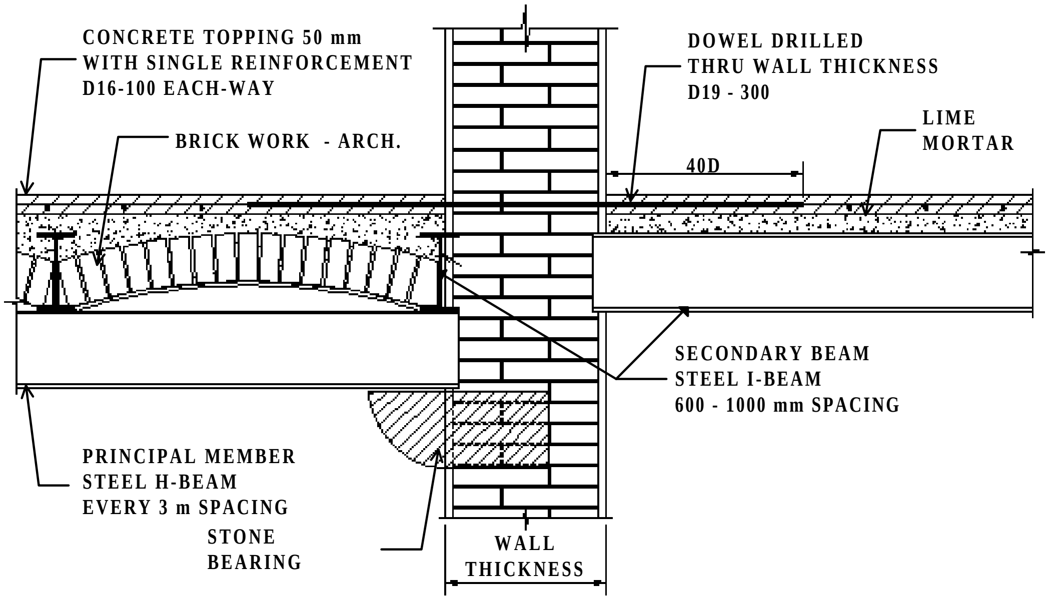

Fig.7 : The Proposed Strengthening System Using Concrete Topping on The Entire Existing Floor Slabs

Table 1 : Lateral Displacement of URM Wall in Y-Direction

Ground Excitation	Node	No Diaphragm Stiffness Without Topping (mm)	Rigid Diaphragm With Topping (mm)
200 YRP	1	44	46.8
	13	123	48.6
	19	95.3	51.1
	69	32.1	54.5
Indonesian 2nd Draft Code 1998	1	21.2	40.1
	13	45	30.2
	19	47.9	29.4
	69	19.3	37.2
20 YRP	1	3.99	21.6
	13	24.1	15.1
	19	14.4	10.6
	69	2.71	3.1