DÖRT KATLI TUĞLA YIĞMA BİR BİNANIN BEŞ ÖLÇEKTE KÜÇÜLTÜLMÜŞ MODELLERİNDE SARMA TABLASI DENEYLERİ

SHAKING TABLE TESTS OF FIVE REDUCED SCALE MODELS OF A FOUR-STOREY BRICK MASONRY BUILDING

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ABSTRACT

The experimental results presented in this paper are part of a Joint Research Project performed between the University of Bologna, Italy and the University of Skopje, Republic of Macedonia. The hypothetical prototype of a simple brick masonry structure with reinforced concrete columns was designed as a representative from the site selected buildings. For this hypothetical structure, a true replica, 1/3 scale model was constructed and tested under various earthquake time histories. Applying different strengthening concepts to the same original model, two strengthened models were built and tested under the same earthquake time histories as the first model. The discussion of the results is done on their difference in the structural behaviour in respect of the variation of the dynamic characteristics, strength and ductility capacity as well as the mechanism of failure. Two of the tested models were repaired by cement injection and tested again under the same experimental programme.

INTRODUCTION

In this paper a part of the results from the research project "Basic and Applied Study for Seismic Modelling of Mixed Reinforced Concrete Masonry Buildings", realized jointly by the Istituto di Tecnica delle Costruzioni and the Istituto di Scienza delle Costruzioni both from the Ministry of Bologna, and the Institute of Earthquake Engineering and Engineering Seismology (IZIIS), University "St. Cyril and Methodius", Skopje, Republic of Macedonia, are presented. Within the scope of this

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project realized in the period 1988 - 1991 eight joint reports have been published covering the entire analytical and experimental results. The primary objective of this project was to develop an appropriate strengthening technology of the existing hotel building in Rimini, constructed as a mixed structural system of brick masonry and reinforced concrete. The first storey of these buildings is mainly constructed of RC beams and columns and brick walls, while the upper storeys are constructed of brick masonry.

For such buildings, the selection of the strengthening strategy depends upon many factors among which are the age of the building and its historic value, the quality of the used structural materials and structural system, the expected seismic hazard level, the soil conditions, the geometrical configuration, the category of building, the urban disposition, etc. All these factors, along with the economic value of the building, have an essential influence upon the decisions of the engineers who has to apply a particular strengthening technology for a particular case. The strengthening demands determine the strengthening strategy that has to provide the required seismic safety of the considered case. Based on the gathered knowledge and experience, the strengthening demands are classified into the following categories: to increase the strength, to increase the ductility, to control structural behaviour, and combination of the above three aims.

In the research part of this project, dealing with the shaking table tests, the strengthening technology was proposed to be a combination of increasing both strength and ductility and, additionally, with combination of structural control behaviour. The differences of the studied technologies are discussed in this paper in terms of changing of the dynamic properties, increasing of the strength the and ductility capacity and the mechanism of failure.

DESCRIPTION OF THE SHAKING TABLE MODELS

Out of several pre-selected buildings at the site, one of them was selected to be the most reliable representative of all the hotel buildings in Rimini. This hotel building has four storeys. The structure of the first floor consists of RC beams and columns and several brick walls, while the upper three floors are constructed in a brick masonry. Based on forced and ambient vibration measurements and mathematical modeling of the prototype building, a hypothetical building consisting of four floors has been designed. For this hypothetical building the torsional effect was neglected to, by which are eliminated most of the already existing uncertainties. Also, for this hypothetical building a true replica model was designed in a geometrical scale 1/3 using the similitude requirements presented in Table 1.

Based on the above scaling requirements, appropriate model materials have been developed. So, for the regular brick size of 25x12x6,5 cm, a brick model of 8x8x4 cm in size of the same material, quality and technology as the prototype brick was produced. According to the similitude requirements, the Young's moduli of the mortar are approximately two times lower, compared

Table 1. Similitude ratios of the models

Similitude parameters	Scaling factors	Model value
Length	$L_r = L_r$	$1/3\ L_p$
Time	$T_r = (L_r)^{1/2}$	$0.577\ T_p$
frequency	$f_r = 1/T_r$	$1.730\ f_p$
Velocity	$V_r = (L_r)^{1/2}$	$0.577\ V_p$
Acceleration	$a = 1$	1.0
Ductility	$\rho_r = E_r/L_r$	$1.5\rho_p$
Strain	$\varepsilon_r = 1$	1.0
Stress	$\sigma_r = E_r$	$0.5\sigma_p$
Young's Modulus	$E_r = 1/2$	$0.5\ E_p$
Displacement	$d_r = L_r$	1/3
Inertia force	$Fr = E_r L_r^2$	$1/18F_p$

to the prototype ones, and the same applies to the concrete material as well. The model was designed using the geometrical scale of 1/3. In need of space, the geometries of the three models are shown in the same figures whereby.

Basically three fully identical models were considered. Model 2 and model 3 were strengthened applying two completely different methods, while model 1 was considered to be the original and it was treated as a reference model. Model 1 and model 3, after testing up to a significant level of damage, were injected by special mortar and tested again under the same loading conditions as models 1, 2 and 3.
The geometrical properties of all the models are shown in figures 1 and 2, while the cross section of model 3 is presented in figure 3. Strengthening of walls 1 and 2 by RC jackets of model 2 is shown in figure 4 while details of corner strengthening of the same model is shown in figure 5.

The model 3 was strengthened by a centrally located RC core. The RC core at the base is designed in such a way (figure 6) that it allows rocking of the base up to the certain level. So, the bending bearing capacity of the core at the base is significantly reduced.

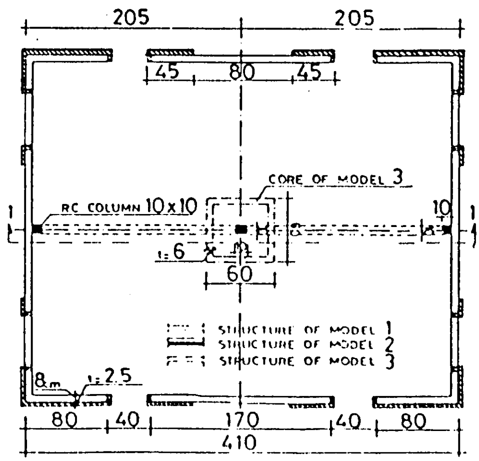

Figure 1. Plan of basement of three models

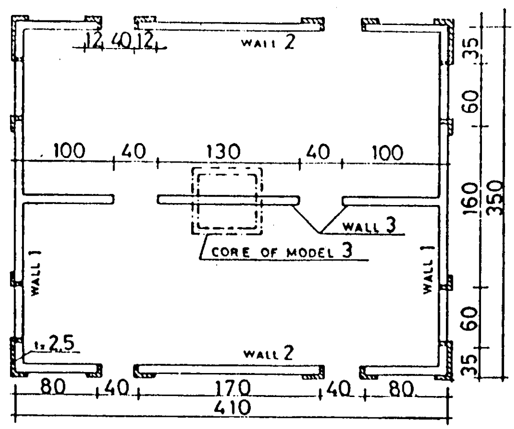

Figure 2. Plan of 2-nd and 3rd floor of all three models

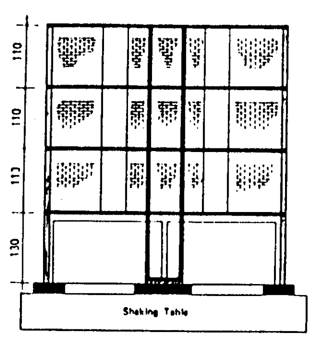

Figure 3. Cross-section 1—1 for model 3

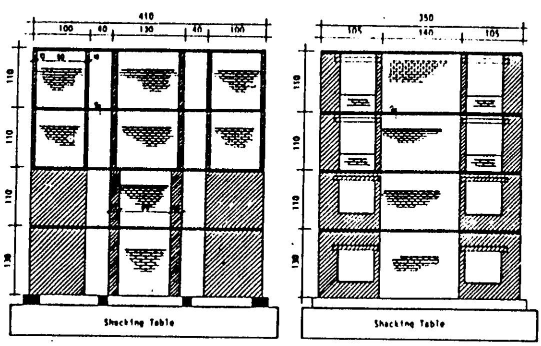

Figure 4. Strengthening of walls 1 and 2 for model 2

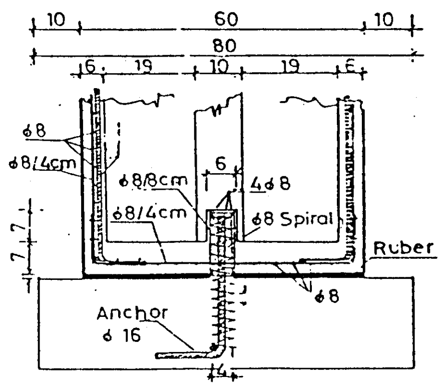

Figure 5. Connection between central core and foundation

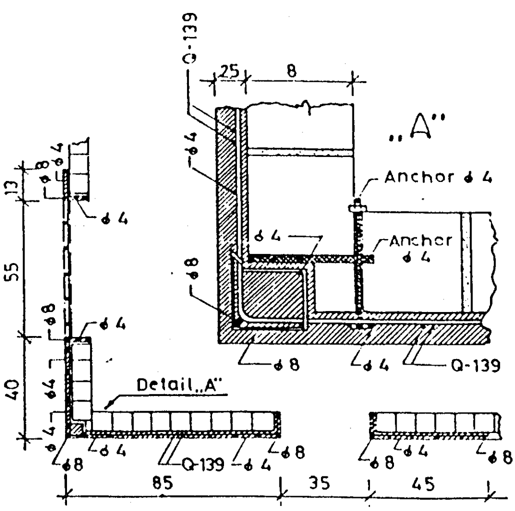

Figure 6. Detail of corner strengthening of model 2

DESCRIPTION OF THE TESTS

The testing of all the models is performed on the biaxial shaking table at the Dynamic Testing Laboratory of the Institute of Earthquake Engineering and Engineering Seismology, in Skopje. The models, with a total mass of 170 kN, for model 1, and up to around 200 kN, for models 2 and 3 and a height of 4.6 m were constructed on the shaking table, 5m x 5m in plan. Since the bearing capacity of the crane is 100 kN, the third and the fourth floor of the models had to be constructed on the shaking table itself. Consequently, the models were constructed and transported without initial cracks.

The experimental programme consists of two parts:

- Definition of the dynamic characteristics of the models (natural frequencies, mode shapes and damping capacities) using the forced vibration method, impulse excitation and random motion test.
- Seismic excitation, using five different earthquake time histories (El Centro 1940; Parkfield 1966; Montenegro 1979, records obtained at Bar, Petrovac and Friuli 1976 records at Breginj, Slovenia).

For recording of the dynamic response of the model, a data acquisition system was used consisting of 30 channels, out of which 6 accelerometers, 13 displacement transducers (LVDT's), 4 linear potentiometers, 2 clip gages and 3 strain gages.

The definition of the dynamic characteristics was carried out at the beginning, then after a number of earthquake simulations , and at the end of the testing. From these tests, the relationship of the natural frequencies reduction upon the level of cracking was obtained.

In the beginning, seismic testing of the models was carried out for all five earthquake types in linear range, in order to determine the sensitivity of the models to the considered earthquake time histories. For this purpose, 15 runs were performed, and then, the testing was continued applying El Centro, Friuli (Breginj) and Montenegro (Petrovac) earthquakes. Applying these three earthquakes, totally 28 runs were performed, until the appearance of visible nonlinearity, and then simulation with only the Petrovac earthquake was carried out until the occurrence of considerable damage to the model.

The above testing scenario was performed for all the models, simulating always earthquakes of the same acceleration on the shaking table. Having in mind that models 2 and 3, compared to model 1, are of considerably higher strength, destructive tests were performed only with the Petrovac earthquake and for significantly higher peak acceleration level of the shaking table. The maximum simulated peak acceleration was 0.51 g, for model 1, and 1.07 g, for models 2 and 3.

STRUCTURAL BEHAVIOUR

Out of the significant volume of experimental results, obtained by the performed tests on the models, consideration in this paper will be given to the dynamic characteristics, models bearing capacity and the failure mechanism. The experimental values can be easily compared, since in all the cases the same monitoring system and the same data processing and data presentation pattern as well as the same order of earthquake simulation on the shaking table was applied.

The dynamic characteristics were defined applying the known methods in experimental mechanics. It is interesting to be pointed out how the resonance frequency was modified depending on the previously generated acceleration level on the seismic shaking table, i.e., the intensity of the micro and macro cracks of the model (figure 7). It is obvious from this figure that model 3 has the highest initial stiffness, then model 2 and, finally, model 1. However, on the other hand, the stiffness deterioration is the lowest for model 1, while model 2 and model 3 show identical behaviour. The model shapes are characterized by prevailing shear type (models 1 and 3), while model 2 has prevailing bending type of vibration. The viscous damping coefficient, defined from the frequency response curves, in all the three cases, range between 2 and 3%. The torsional frequency is twice the value of the first frequencies of the translation al mode shapes.

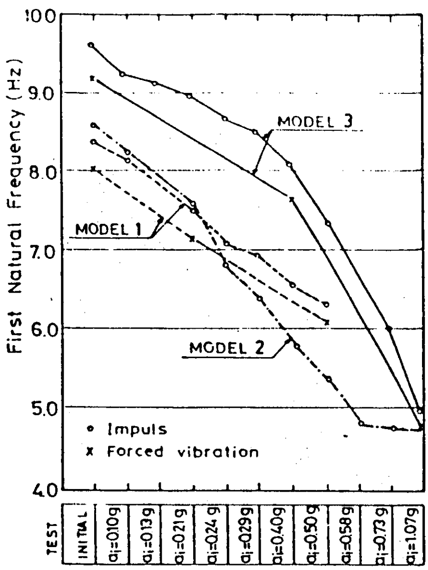

Figure 7. First natural frequency decreasing as a function of peak shaking table motion for all tested models

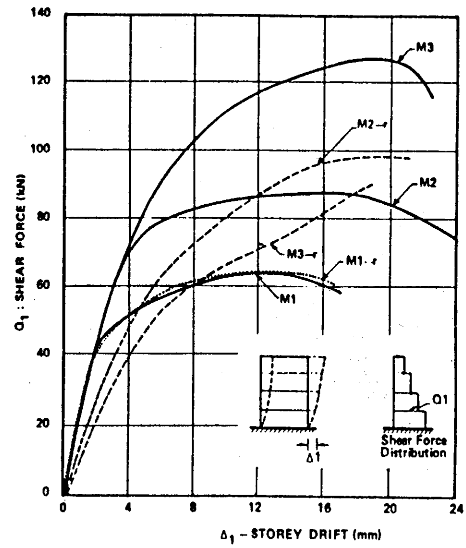

Figure 8. Shear force – storey drift relationship – first floor

The relationship of the shear force of the first floor in function of the relative storey displacement, for all the tested models, is presented in figure 8.

This figure shows the variation of the initial stiffness of the models, changing of the ductility and the ultimate strength capacity. It is obvious from this figure that the highest strength capacity is observed for model 3, while the lowest one for model 1. Model 1, repaired by special cement injection, has almost the same structural behaviour as the original one, while model 3, repaired with the same injection material as in the case of model 1, shows quite a different behaviour than the original model 3. The difference in the behaviour results from the fact that only the brick walls were repaired by injection, but not the RC core, which had also cracks along its height.

Based on the analysis of the damage mechanisms of the five tested models, because of the limited space of the papers, which does not allow their graphical presentation, the following conclusions can be drawn regarding their spatial distribution:

- The damage mechanism of model 1 is located at the first floor and it is both of shear and bending type.

- Model 1, repaired by cement injection , is characterized by considerable damage to the second floor and very slight damage to the first floor, but at a completely different location, compared to the cracks which developed in the case of the original model 1. Disattachment of the injected mass from neither the brick nor the mortar was observed.

- In the case of model 2 (model 1 strengthened by RC external walls) the damage mechanism was located mainly in the brick walls of the first, second and the third floor level without external RC walls. The observed cracks were of shear type. In the RC walls, damage was observed in the first floor, prevailing of bending type.

- For model 3, the damage mechanism was uniformly distributed to all the walls from the first to the fourth floor level and it was of prevailing shear type. Some cracks to the RC core were also observed. Such a damage mechanism, corresponding to an ideally designed structure, is imposed by the mechanism of the structural behaviour of the RC core. Namely, the given possibility of the RC core for rocking at the base enables providing of an equal relative storey displacement at each floor level.

Model 3, repaired by cement injection, showed an identical damage mechanism as the original model 3. Namely, cracks were observed along the height of all the walls, from the first to the fourth floor level. The cracks developed along completely new lines compared to those of the original model 3. Disarmament of the injected mass was observed from neither the bricks nor the mortar. No injection of the RC core cracks was carried out. This results into a considerable difference in the overall structural behaviour between original and repaired model 3.

CONCLUSIONS

Strengthening of structures is, in general, a very responsible and complex task which structural engineers are faced with, especially when the strengthening has to be performed by using materials different than those the structure is built of. Each particular case requires a research for itself before decisions are to be made as to choosing the appropriate strengthening strategy. One of the most responsible tasks in making decisions regarding the strengthening strategy is diagnosis of the existing bearing capacity of the structure and the mechanical properties of the used materials and structural elements.

The experimental results, obtained by testing of models, provide a sufficient volume of data for selection of a technical solution for strengthening of masonry structures, that will insure the required seismic safety of a structure at an economically acceptable cost. The studied strengthening technologies enable application of combined strengthening solutions, depending on the geometry of the structures and their purpose.

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Bu çalışmayla sunulan deneysel sonuçlar Makedonya Cumhuriyeti'nin Üsküp Üniversitesi ile İtalya'nın Bologna Üniversitesi arasındaki ortak araştırma projesinin parçalarıdır. Uygulaması yapılmış bazı yapıları temsil etmek üzere, betonarme kolonlu, basit tuğla yığma bir yapı örnek olarak boyutlandırılmıştır. Bu modelin 1/3 ölçeğindeki benzeri inşa edilmiş ve değişik deprem yükleri için denenmiştir. İlk modele uygulanan değişik güçlendirme yollarından sonra iki güçlendirilmiş model inşa edilmiş ve ilk modele uygulanan depremin etkisinde denenmiştir. Sonuçların tartışması, göçme modları, süneklik kapasitesi, mukavemet ve dinamik özelliklerdeki değişime dayalı olarak yapısal davranıştaki farklılıklar üzerinde yapılmıştır. Denenmiş modellerden ikisi çimento enjeksiyonu ile onarıldıktan sonra, aynı deney düzeni içinde yeniden denenmiştir.