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NEW CONCEPT AND SOLUTIONS FOR POST-SEISMIC ASSESSMENT AND STRENGTHENING OF BUILDINGS

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Abstract

Due to the time evolution of the design provisions, there are buildings that were designed decades ago, using less stringent provisions. Thus, when the earthquake is produced, there are many cases where the buildings are badly damaged. Structural engineering is closely related to parameters such as acceleration, velocity, displacements, and spectral composition, therefore, with the widespread use of strong motions apparatus, in the '70s they started seismic instrumentation with help of seismic stations located in the buildings, dams and bridges. According to the modern approach of the post-seismic investigation the damage building assessment should be clearly foreseen and properly planned in order to obtain dynamic parameters for the analysis. The objectives of the paper are to present both a new concept for building performances assessment and a modern solution for building strengthening. All the aforementioned ideas are illustrated through a study case. The dynamic parameter evolution of 3D model of reinforced concrete at natural scale it will be analysed. In case of masonry panels inserted in reinforced concrete frames a modern and efficient solution is panel strengthened with Carbon Fibers as fabrics and plates. Therefore, the researches on the strengthening solution effectiveness of masonry walls are presented. Experiments on a large scale of modular elements of masonry buildings, tested and strengthened with CF were carried out in Research and Testing Laboratory on Materials, Components and Structures for Buildings - INCERC at universal press 4MN, submitted them to compression on diagonal direction. The results were demonstrated that the application of CF on the masonry panels is efficient, but to optimize costs it is necessary to review the size and disposal of plates used.

Keywords: *seismic action, structural analysis, dynamic parameters, strengthening works, Carbon Fibers*

INTRODUCTION

To analyze the behavior of buildings, after each strong earthquake, authorities, owners and professionals take as a reference the intensity of the seismic movement on that site. Structural engineering is closely related to parameters such as acceleration, velocity, movement, and spectral composition; therefore, with the widespread use of strong motion resistant seismographs, the seismic instrumentation has been started, by installing stations in constructions, dams, bridges etc.

In the U.S., the provisions of the most well-known construction regulatory - Uniform Building Code, recommends for seismic zones 3 and 4 the installing of accelerographs in the new tall buildings with more than six stories high and a total area of at least 5574 m2. In general, it is required to install at least 3 devices: at the base, in the middle and at last level of the building, devices interconnected to trigger simultaneous and with common sampling and time base. In buildings with more than 10 levels, without taking into account the area of construction, the seismic instrumentation is mandatory and there must be provided at least three triaxial accelerographs.

The seismic information system for emergency response CUBE (initiated in 1990 by Caltech and USGS Pasadena), transmits data within minutes with the magnitude and epicenter of an earthquake to the civil defense agencies, authorities, private companies, and the Automated Monitoring Of Earthquake Strong-motion (AMOES) provides rapid measurements of the acceleration of strong seismic movements through INTERNET.

In Japan, the seismic networks have been developed and equipped with a large number of devices by using funds of the Ministry of Construction, through care of the research institutes in the construction sites for large ports, bridges, tunnels and buildings.

After the Kobe earthquake in 1995, a new strong-motion earthquake recording network K-NET (Kyoshin) was implemented, based on 1000 new specially-designed seismic stations, with INTERNET communication capability; the K-NET 95 seismographs, installed on the open ground, at an average distance of 25 km can record any earthquake of magnitude 7 in Japan.

Development of seismic networks in Europe has been slower, but now several thousand instruments have been installed.

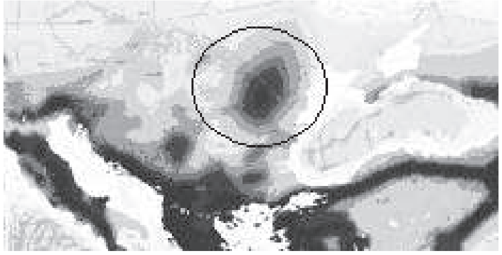


Fig. 1. Seismic map of Europe highlighting the Vrancea area

In Italy, one of the priority projects of the National Seismic Service is On-Building Seismic Observation System, which aims both at building an instrumental network of measuring and recording the seismic response for a significant number of buildings sample and the creation and updating of numerical models for them, using advanced techniques.

In Turkey, besides the recording network of strong-motion earthquakes, which includes over 100 devices, the monitoring system for structural resistance and immediate alarm in case of an earthquake for bridges of greater openness has been developed. Such a system is installed on the new suspension bridge over the Bosphorus.

In Romania, the seismic design code, index P100-1/2006, states in Annex A, the following regarding the future seismic instrumentation for buildings in Romania:

- In seismic areas where the design acceleration value a_g, with IMR (average recurrence) ≥ 100 years is $a_g \geq 0.24$ g, buildings with a height of more than 50 m or more than 16 stories high or with a surface area of over 7500m^2, will be instrumented with a digital acquisition system and minimum 4 (four) triaxial acceleration sensors.
- This minimal instrumentation will be located as follows: 1 senzor in the open field, near the construction, 1 sensor in the basement and 2 sensors on the top floor. Instruments will be placed so that access to equipment could be possible at any time.
- Instrumentation, maintenance and operation is funded by the building owner and undertaken by approved organizations.
- Records obtained during strong earthquakes must be made available to the competent authorities and specialized institutions in 24 hours from the earthquake occurence.

The cost of seismic data acquisition system is low compared to the total value of a multi-story building, with finishes, furnishings, modern facilities and equipment, or to that of an industrial investment, which would otherwise be decommissioned pending the traditional expertise.

Proper understanding by the designer of the importance and influence of different factors on the structural dynamic response and their correlation with the beneficiary's objectives of interest, leads to a choice and to a suitable distribution of the seismic monitoring systems components in the building.

Overall, the measurement of the own vibration period may reveal a number of structural damage, endured by the structure until the moment of measurement; measuring this size, before and after the earthquake, is a comprehensive method for assessing changes in the rigidity of a construction due to seismic stress, noting that rigidity such highlighted corresponds to low levels of stress.

MATERIAL AND METHOD

Modern concept of post-seismic structures investigation

The experimental model presented in the case study was conducted in 1990-1991 in the seismic Hall of INCERC Bucharest, in view of full-scale tests.

The construction is based on a modular square grid 3.90 x 3.90 m and a floor height of 2.75 m, consisting of two openings and two bays, which comprises a single structural wall.

At the intersection of axes, constant cross-section poles are placed, 500 x 500 mm, covering the entire height of the building. Pillars are prefabricated for two-story height, with a non-concrete portion in the middle of 350 mm, which includes reinforcement of strips of plate. Full-scale tests were conducted as follows [1]:

- The first step of testing the experimental system was to load the tare weight and more concrete weights.
- In 1995 took place the first test with lateral loading forces, using presses, while in 1996 post-elastic horizontal loads were applied, in 8 cycles (incremental loads).
- In 1997 the experimental model testing was resumed, aiming at the evaluation of the behavior to breaking stress.

To simulate the behavior of a future earthquake damaged building, the following steps were followed:

- Determination of the own vibration periods by microseism measurements and their processing;
- Modeling a spatial structure identical to that found in seismic Hall; noting that the model was created with five levels unlike the existing one that had four levels (being tested at the top--floor - terrace to simulate the loading of an extra floor).
- The time-history analysis to determine the structure response spectrum using accelerograms recorded in the earthquakes in from the '77, '86 and '90.

Following the above steps, microseism measurements were made on the experimental model, following two sensor placement schemes presented in Fig. 2. Measurements were made both by applying shocks in the center of the 2nd floor and the microseism movement from the site.

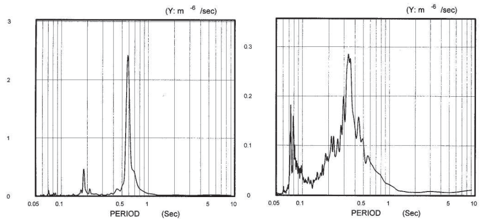
Microseism measurement results obtained in the case of the full-scale experimental model, with GF+3 floors are presented in Table 1. These values of own periods of vibration are determined from the Fourier spectrums. Processing the records made at this stage of cracking of the model are presented in Fig. 4 [4].

Fig. 2. *Full-scale experimental model*

Fig. 3. *GEODAS 12-USB, 12-channel seismic station, Buttan Service, Japonia*

Table 1. *Dynamic characteristics of the experimental model in the present state of cracking*

Equipment / Program used	$T_{dir. x}$ (s)	$T_{dir. y}$ (s)
GEODAS 12-USB, Buttan Service, Japonia /Microwave tremor observation	0.60	0.32



a) x direction b) y direction

Fig. 4. The *response spectrums obtained by processing the microseism records*

For structural calculation, the following material characteristics were used:

- Concrete features: elastic modulus E=22.500 MPa, the weight per voume unit $\rho_W=23$ kN/m^3.
- Steel features: elasticity modulus E=199.900 MPa, the weight per voume unit $\rho_W=77$ kN/m^3.

$T_1=0{,}64$s z-x plane; $T_2=0{,}49$s x-y plane; $T_3=0{,}34$s y-z plane

Fig. 5. *Own modes of vibration. System dynamic characteristics*

Note: reinforced concrete diaphragm is arranged by the structural model y direction.

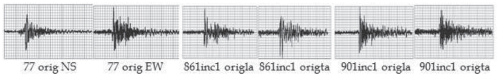
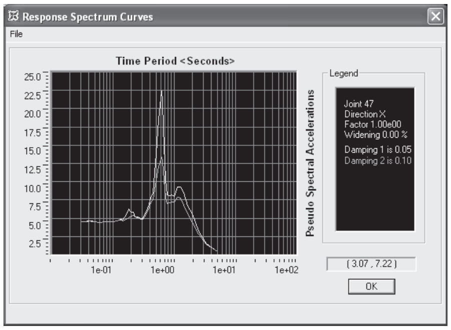


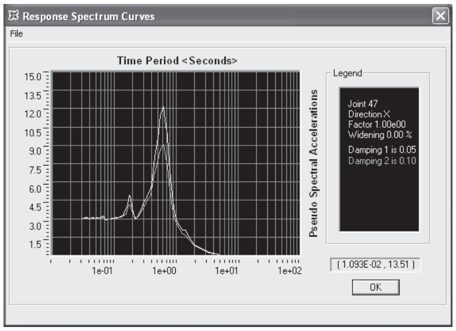
Fig. 6. *Accelerograms used in the time-history analysis*



Joint 47
Direction X
Factor 1.00e00
Widening 0.00 %
Damping 1 is 0.05
Damping 2 is 0.10

(3.07 , 7.22)

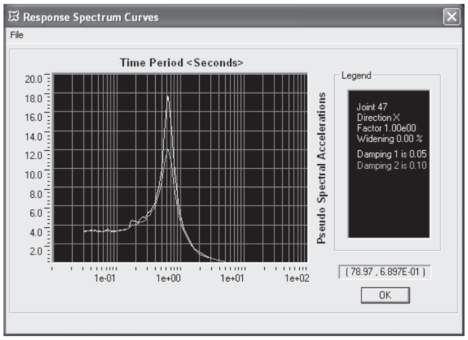
Fig. 7. *The response spectrum obtained at the top level of the structure for the accelerogram recorded on the N-S direction in the '77 earthquake, applied to x direction*



Joint 47
Direction X
Factor 1.00e00
Widening 0.00 %
Damping 1 is 0.05
Damping 2 is 0.10

(1.093E-02 , 13.51)

Fig. 8. *The response spectrum obtained at the top level of the structure for the accelerogram recorded on the longitudinal direction in the '86 earthquake, applied to x direction*



Joint 47
Direction X
Factor 1.00e00
Widening 0.00 %
Damping 1 is 0.05
Damping 2 is 0.10

(78.97 , 6.897E-01)

Fig. 9. *The response spectrum obtained at the top level of the structure for the accelerogram recorded on the longitudinal direction in the '90 earthquake, applied to x direction*

The linear modal time-history analysis provides the results as graphs and comprise, for the structural system studied, the movement and acceleration variations versus time, in a node at the top level and at the level 1.

RESULTS AND DISCUSSIONS

Regarding the movements, the results are shown in Fig. 10 and Fig. 11.

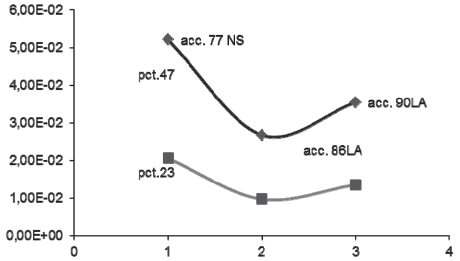


Fig. 10. *Maximum values of movements in the x direction, corresponding to nodes 47 and 23 at different earthquakes ('77, '86 and '90)*

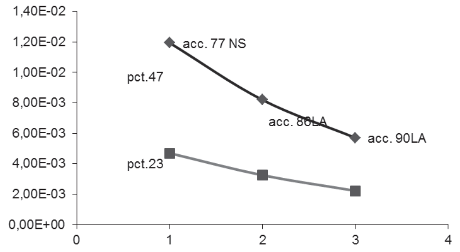


Fig. 11. *Maximum values of movements in the y direction, corresponding to nodes 47 and 23 at different earthquakes ('77, '86 and '90)*

- In terms of accelerations, the results are shown in Fig. 12 and Fig. 13.

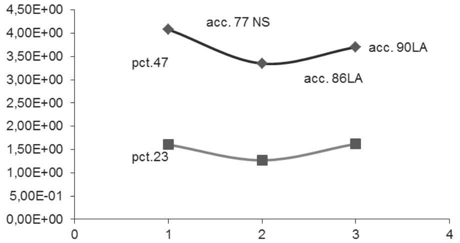


Fig. 12. *Maximum values of accelerations in the y direction, corresponding to nodes 47 and 23 at different earthquakes ('77, '86 and '90)*

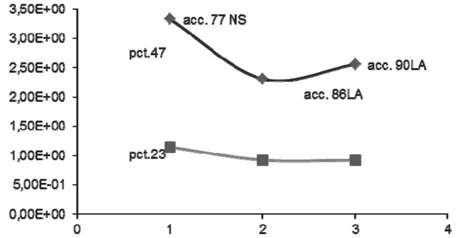


Fig. 13. *Maximum values of accelerations in the x direction, corresponding to nodes 47 and 23 at different earthquakes ('77, '86 and '90)*

Solutions to strengthen the masonry panels in reinforced concrete frames structures

To highlight the efficiency of carbon fiber reinforcement, the full-scale attempts made in the INCERC Bucharest laboratories are presented. The masonry panels presented are made of ceramic blocks with vertical hollows.

Strengthening with carbon fiber strips

The basic concept of the experiments was to use a standardized test - *the diagonal test* – on the same specimens of masonry in two situations: in the initial state, masonry made according to usual procedures and after applying a reinforcement with carbon fiber strips attached to specific adhesives [3].

The results indicated that the tested systems are effective, with the clarifications that it is also advisable to apply the strips on the diagonal of the panels in two directions close to the main efforts, so that the strips work on stretching. In this case, it would be reasonable to recalculate the size and arrangement of the strips used, for cost optimization.

Fig. 14. Making specimens, by applying the Carbodur S 1012 strips

Since parametric testing was done in one direction, in static stress, monotone increasing, while the real seismic application is dynamic in nature, it is necessary to extend the research, to highlight the differences in behavior. It is advisable to symmetrically apply the strips on both sides of the specimens, as consolidation on only one side can cause failure by bending in a direction normal to the sample plane, at forces below the original test. The application process can be done on masonry with superior resistance characteristics, thus ensuring the entry into work and working together between the two materials during the stress application, avoiding crushing masonry in the nodes areas. From this point of view, because in practical applications two diagonal strips are applied, at higher levels of alternating stress, it is possible that masonry work stop of the corners of the frame may occur successively, where the grip is redundant, the rest of the strip remaining as active zone, on the long direction, but with some contribution of the strips from the other direction. These considerations should be taken into account in determining the actual size of the strips area of contact with the masonry, in relation to the computing area. If anchoring the strips to concrete slabs on the contour, some of these effects may be compensated, the strips may work efficiently throughout the whole stress application. Additional tests are needed to clarify the concrete behavior particularities and the strips adherence to concrete in the node zone.

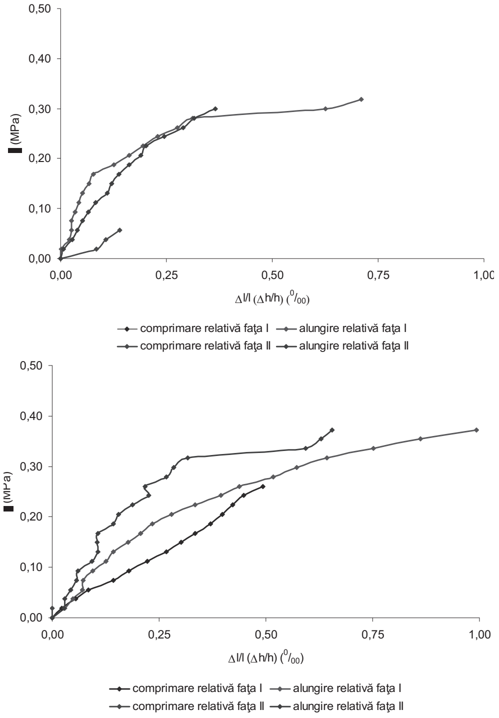


Fig. 15. *Relationship between effort - relative compression / relative elongation corresponding for two of the samples tested*

Strengthening masonry panels with carbon fiber fabric

The aim of the trials carried out at INCERC was to test for bending four models of masonry made of ceramic blocks, with the same plan dimensions 1.50 x 1.00 m, but with different thickness: 2 models with 30 cm thickness (M30) and 2 models with 38 cm thickness (M38) [2].

Attempts have been made at various stages, as follows:

- In the first stage two models of simple masonry (different thickness) were tested;
- In the second stage the other two models were tested, but this time they were consolidated on the side with fabric from reinforced carbon fiber. The test results of the two stages will be presented in comparison to highlight the effectiveness of consolidation.

The two models tested in the second stage were consolidated on the side with carbon fiber fabric from ISOMAT, MEGAWRAP type. To apply this fabric, a bicomponent Epoxy resin was used, from the same company, type EPOMAX-LD.

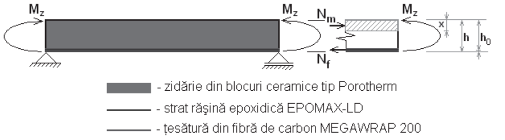


Fig. 16. Schema de calcul a secțiunilor dreptunghiulare la încovoiere

To highlight the need to strengthen with a larger or smaller number of carbon fiber fabric layers, the model with 30 cm thickness was coated with two layers of fabric overlapping on a width of 20 cm, while the model with 38 cm thickness was coated on the side with only one layer. In Fig. 16, a calculus scheme to determine the required reinforcement area at stretched fiber.

From the balance equations results that:

$$M_z = N_m h_m$$

$$\begin{cases} N_f = N_m \\ N_f = A_f f_f \Rightarrow x = \dfrac{A_f f_f}{b f_m} \\ N_m = bxf_m \end{cases}$$

where x is the height of the compressed zone (neutral axis position).

$$\begin{cases} M_z = N_m h_m \\ h_m = h_0 - \dfrac{x}{2} \end{cases} \Rightarrow M_z = bxf_m (h_0 - \frac{x}{2}) \Rightarrow M_z =$$

$$= bxf_m h_0 - b\frac{x^2}{2} f_m \Rightarrow M_z = A_f f_f h_0 - \frac{(A_f f_f)^2}{2bf_m} \Rightarrow$$

$$(A_f f_f)^2 - 2bf_m h_0 (A_f f_f) + 2bf_m M_z = 0$$

The acceptable solution of the second degree equation is:

$$A_f f_f = bh_0 f_m \left(1 - \sqrt{1 - \frac{2M_z}{bh_0^2 f_m}}\right) \Rightarrow$$

$$A_f = \frac{bh_0 f_m}{f_f}\left(1 - \sqrt{1 - \frac{2M_z}{bh_0^2 f_m}}\right)$$

where A_f = area of the carbon fiber fabric.

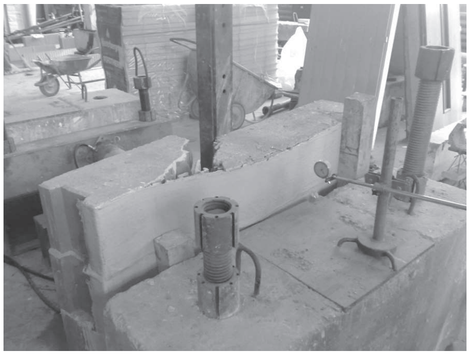


Fig. 17. *The M30 model after failure*

In Fig. 18 and Fig. 19, the force-arrow diagrams are shown in comparison, with the two versions of the M30 model: unconsolidated and consolidated.

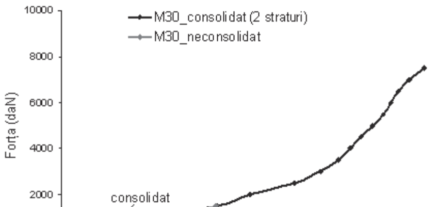


Fig. 18. *Force-arrow diagram for the M30 masonry model (30 cm thick)*

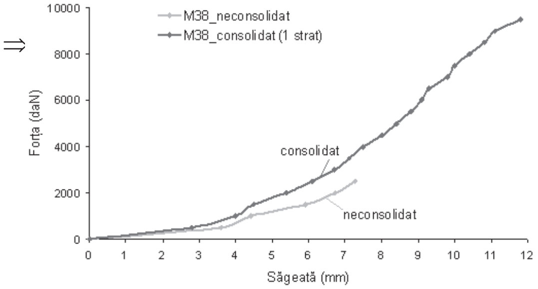


Fig. 19. *Force-arrow diagram for the M38 masonry model (38 cm thick)*

Comments

- Results demonstrate the efficiency obtained for the application of layers of carbon fiber fabric on the model stretched fiber.
- After the failures of the two modules, was found that the masonry failed, as expected, because it exceeded the compressive resistance on the compressed side.
- Under the conditions of these tests, the contribution to the rigidity conferred by the blocks size was greater than the contribution given by applying a double number of layers of carbon fiber fabric;
- Because the failure point doesn't appear in the zone of the stretched fiber, where for fabric is applied, but in the compressed side with simple masonry, a single layer of fabric is enough, because the advantage of an increased number of layers may not be exploited.

CONCLUSIONS

The concept of investigating the performance of a building proposes the validation of calculations with a program dedicated to structural analysis using instrumental data processing techniques.

Based on the results obtained on site with the GEODAS 12-USB seismic station, Buttan Service, Japan, a structural model with identical dynamic characteristics has been modeled and thus the behavior of the existing structure to strong earthquakes in Romania has been studied. We can say that in this way one can predict how certain structures that have experienced earthquakes in the last century will respond to future earthquakes.

In the case of the modern solutions to consolidate masonry panels, the results obtained in both cases of consolidation have revealed positive values for applying the solution. In addition, these consolidation solutions are differentiated from the traditional solutions through the reduced execution times.

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