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Vibo Valentia, Italy

Ref: *Summary Observations on ENEA Seismic Verification Tests*

The following pages, a summary report for my observations and analysis of large-scale shake table tests that were conducted at ENEA facility in Rome, Italy in May 2015 that I have witnessed.

In addition, a general description and my opinion on the "Pillar Bone" patented technology developed by EDILINNOVA Ltd. for rehabilitation and upgrade seismic capacity of existing and new columns, including pervious verification tests that were performed by both CTM and University of Naples are included.

Sincerely,

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1. ABSTARCT

This report summarizes the observations on the large-scale shake table tests that were conducted at ENEA facility in Rome, Italy in May 2015 that I have witnessed. All large-scale test specimens were fabricated in accordance to NTC2008 requirements.

In addition, a general description and my opinion on the "Pillar Bone" patented technology developed by EDILINNOVA Ltd. For rehabilitation and upgrade seismic capacity of existing and new columns, respectively is included.

2. DESCRIPTION OF THE EDILINNOVA INNOVATIVE PILLAR BONE REHABILITATION TECHNOLOGY

The main idea of this technology is to decouple between flexural and gravity demand in a reinforced concrete column subject to seismic forces. During a seismic event, the RC columns are subjected to cyclic loading due to ground motion. The majority of the damage will occur at the extreme fibers of the columns including the unconfined cover shell. Depending on the confinement reinforcement details, rupture of ties or hoops will result in local buckling of the flexural steel reinforcement creating large displacement that lead to the formation of plastic hinges at different location of the columns and beams in a typical RC frame structure. Once the outer portion of the concrete and exterior reinforcements degraded, a total collapse may occur due to the inability of the building of withstanding the imposed gravity load. In this methodology, a gravity reinforcing core is installed at the central zone of the column in addition to the exterior flexural reinforcing rebars (see Figure 1). In this scenario, while potential major deterioration occurs to the exterior portion of the column, a relatively minor damage will developed at the central reinforced core providing the needed axial capacity to carry the imposed gravity load after ground motion decay. The presence of the gravity-resistant reinforced core section will also provide additional rigidity to the column. A simple analogy for this technology is the human leg. If the lower portion mussels of the leg is wounded or if the exterior "*fibul*a" bone fractured, while the internal "*tibia*" bone is still intact, a person can still carry the human body weight, may be with some limping (see Figure 2-a). However, if the internal "*tibia*" bone fractured, or if both the internal "*tibia*" and the exterior "*fibul*a" fractured, it would be very difficult for a human to carry his/her own weight as shown in Figure 2-a. Figure (2-b) shows the results of a large-scale column specimen that was tested under sever cyclic loading. As seen in this figure, a major deterioration occurred to the exterior portion of the column, while the core portion had minimal damage.

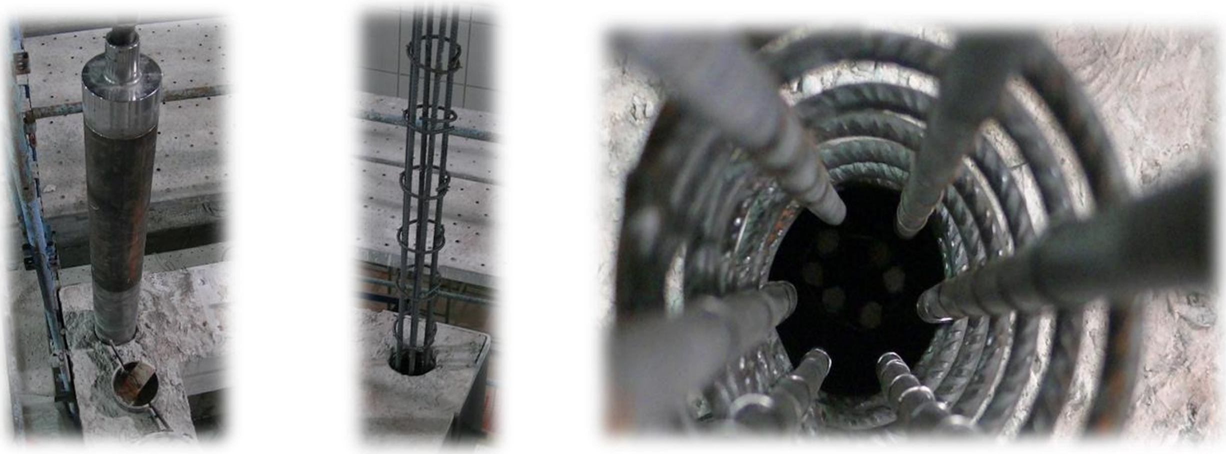
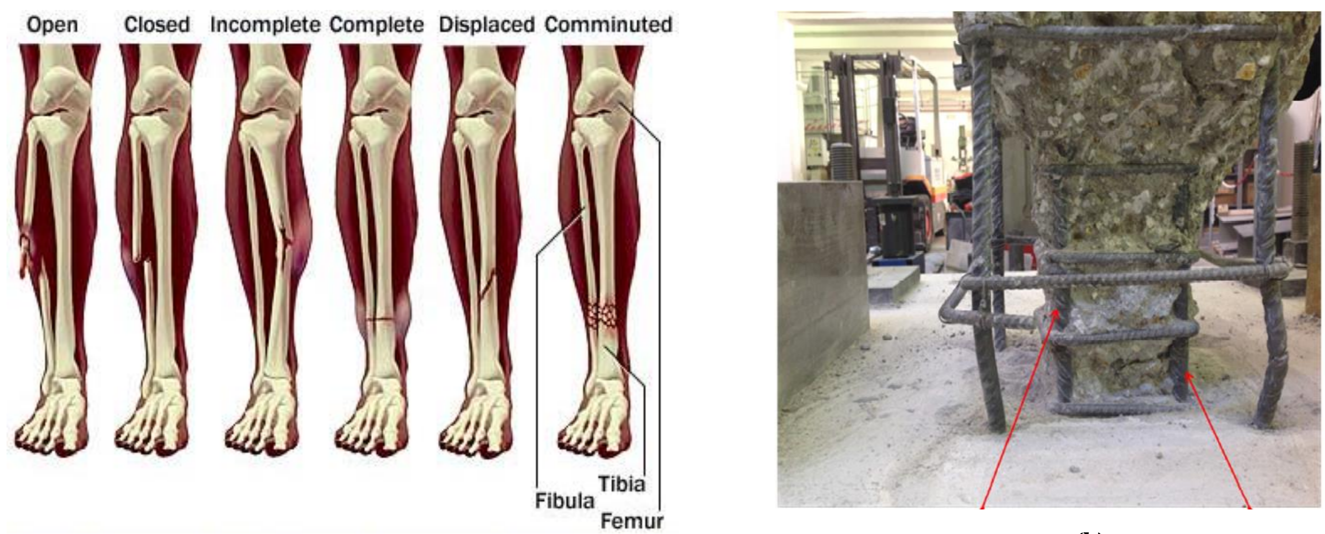


Figure (2): Installation of EDILINNOVA Pillar Bone Rehabilitation Technology for Existing Reinforced Concrete Building



(b)

(a)

Figure (2): ***(a)*** *Analogy of Human Leg Bones,*
(b) *A Column with Pillar Bone Core System after Ultimate Cyclic Loading.*

3. SUMMARY OF THE ENEA SHAKE TABLE TESTS

In May 2015, I have been invited to witness large-scale, shake table verification tests that were performed at the ENEA UTTMAT-QUAL ENEA laboratory. In addition, assurance of test setup and equipment calibration were performed.

The overall objective of the large-scale shake table tests is to verify and confirm the effectiveness of the system and to compare the results to both the monotonic and cyclic tests that were performed in previous test program that were conducted at both the Southern Technology Centre (CTM) and University Napoli on the performance of the EDILINNOVA Pillar Bone system. Three 2-story reinforced concrete frame structures were fabricated at ETNA and were instrumented and were later subjected to identical ground motions (see Figure 3). Table (1) shows the description of each specimen. Figure (4) shows the typical 2-story frame structures specimens evaluated in this program.

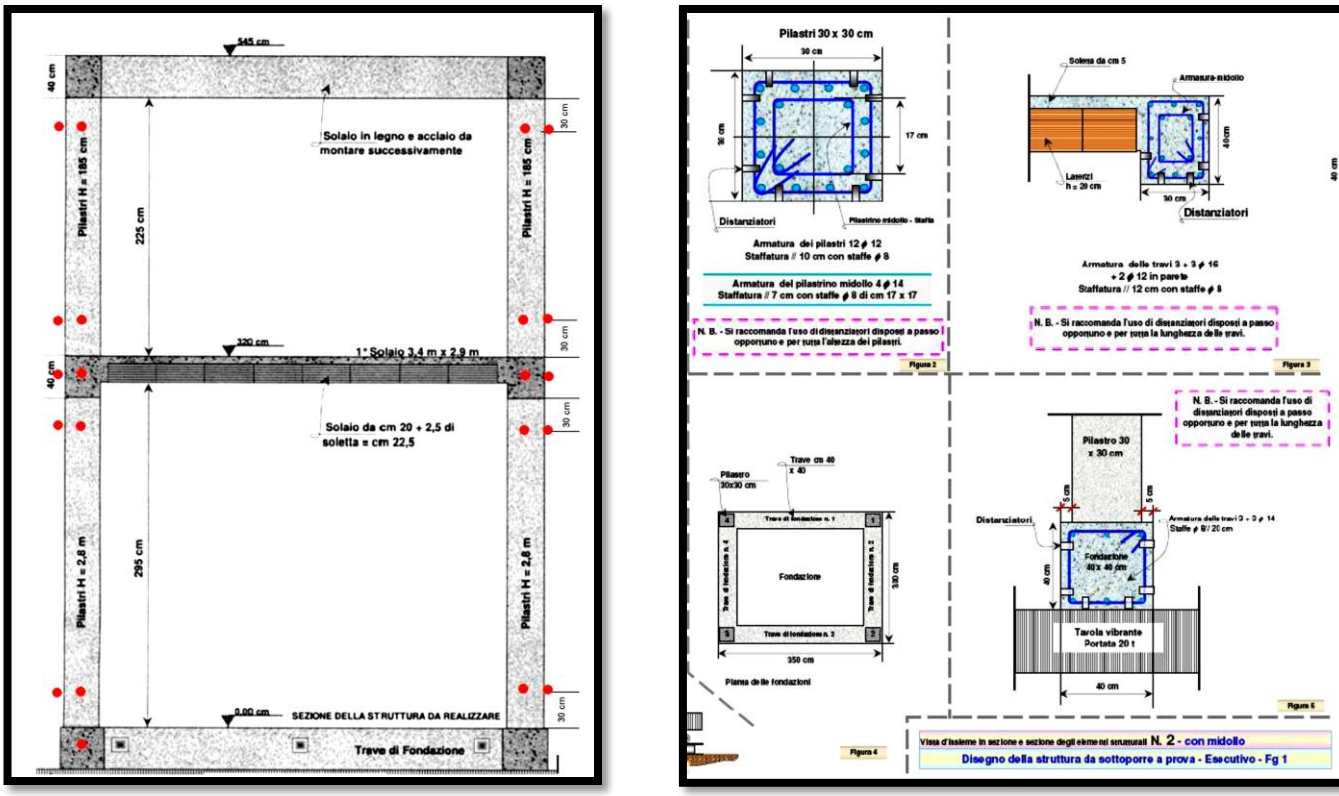


Figure (3): Typical Dimensions and Geometry of 2-Story Frame Structure Specimens
[Source: ENEA UTTMAT-QUAL Report RT_08-2015]

Table (1): Description and Target of Each 2-Story Frame Specimen

SPECIMEN ID	DESCRIPTION AND TARGET
A	A control (*As-Built*) Frame Specimen built in accordance to NTC2008
B	A Specimen Simulating a *New Building Design* with Pillar Bone Core System
C	A Specimen Simulating a *Rehabilitated Existing Building* using Pillar Bone Core System

Figure (4): Typical 2-Story Reinforced Concrete Frame Structure Specimens

The acceleration of each large-scale specimen was monitored using twelve calibrated electronic accelerometers including three accelerometers installed in each floor in addition to three accelerometers to monitor and control the shake table. The locations of the accelerometers are shown in Figure (5). In of the use of electronic accelerometers, an electronic system for capturing the 3D motion (called 3DVision) was also used.

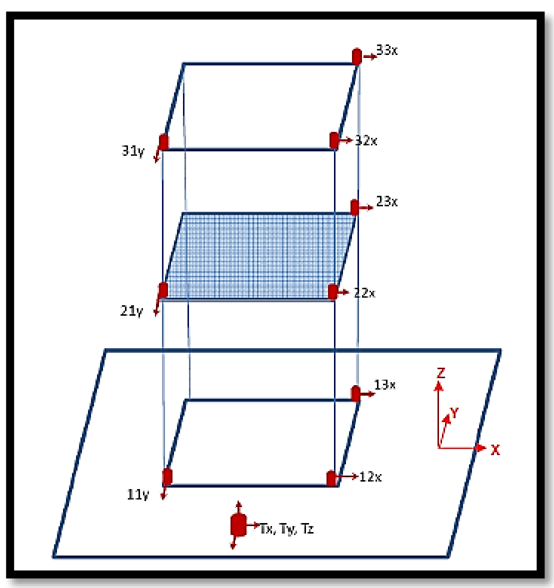


Figure (5): Typical Electronic Accelerometers Locations
[Source: ENEA UTTMAT-QUAL Report RT_08-2015]

All tests were witnessed remotely by about 200 professional via internet using the (Structural Dynamics, numerical Simulation, qualification tests and vibration control (DySCo) virtual laboratory (see Figure 6).

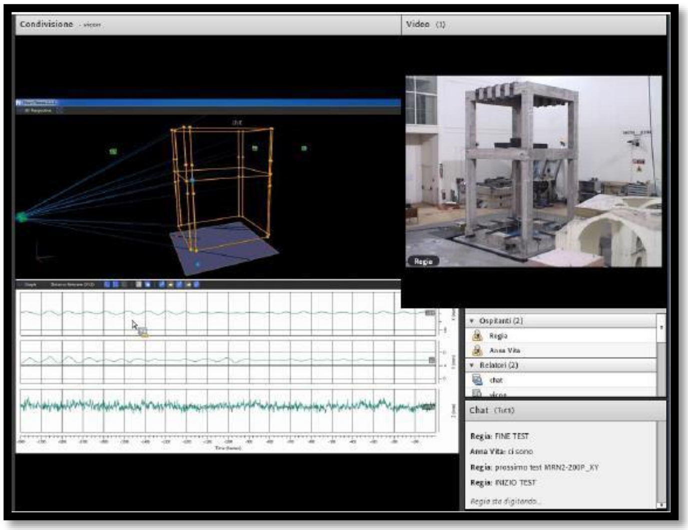


Figure (6): Remote Witnessing via Internet for about 200 Users
Using DySCo Virtual Laboratory (Building Model "**B**")
[Source: ENEA UTTMAT-QUAL Report RT_08-2015]

Figure (7) shows a Schematic Section of the 4.0 m X 4.0 m a 6GDL Shake Table used in Evaluating EDILINNOVA Innovative Pillar Bone Rehabilitation Technology. The technical specifications of the 6 DOF shake table (see Figure 7) are presented in Tables (2) and (3).

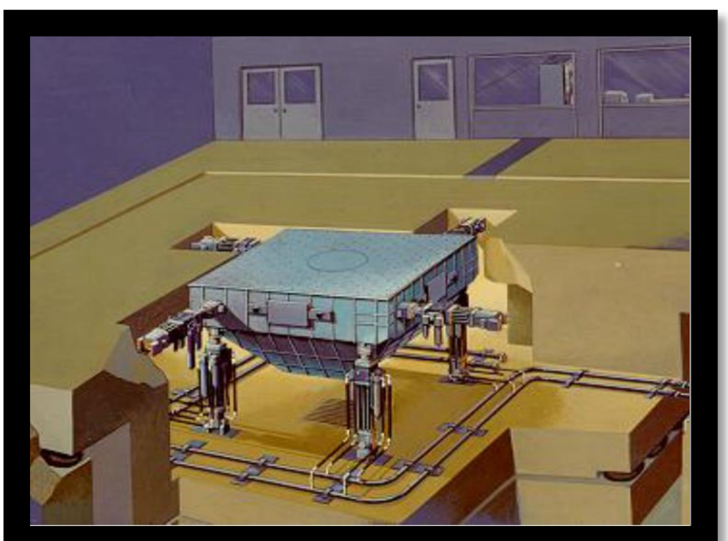


Figure (7): Schematic Section of the 4.0 m X 4.0 m a 6GDL Shake Table used in Evaluating EDILINNOVA Innovative Pillar Bone Rehabilitation Technology

Table (2): Technical Specifications of ENEA Two Shake Tables
[Source: ENEA UTTMAT-QUAL Report RT_08-2015 – Translated to English]

	System 1*	***System 2***
Dimensions of Shake Table	4m x 4m	2m x 2m
Degrees of Freedom	6 DOF	6 DOF
Frequency Field	0-50 Hz	0-100 Hz
Acceleration	3g peak	5g peak
Velocity	0.5 m/s (0-peak)	1 m/s (0-peak)
Displacement	0.125 m (0-peak)	0.30 m (0-peak)
Mass and Height of Center of Gravity (C.G.) of Test Specimen	• *10.0 ton* • *1.0 meter height of C.G.*	• *1.0 ton* • *1.0 meter height of C.G.*

**System 1 was used for all EDILINNOVA specimens' tests*

Table (3): Additional Technical Specifications on Shake Table System "1" Used in all Tests
[Source: ENEA UTTMAT-QUAL Report RT_08-2015]

Seismic Table N° 1	
Frequency range (Hz)	**0-50**
Stroke (mm p-p)	
Horizontal	**250**
Vertical	**250**
Max Velocity (m/s)	
Horizontal	**0.78**
Vertical	**0.78**
Max Acceleration at bare table (m/s^2)	
Horizontal	
harmonic	**49**
impulse	**78**
Vertical	
harmonic	**49**
impulse	**78**
Yaw rotation (+/- degrees)	**4.7**
Yaw velocity (rad/s)	**13.03**
Pitch/Roll rotation (+/- degrees)	**4.7**
Pitch/Roll velocity (rad/s)	**13.03**
Max Overturning Moment (kNxm)	**300**
Max Specimen Dead Weight (kN)	**300**
Dead Weight Compensation	

4. TEST PROGRAM SUMMARY

Prior to shake table dynamic tests, each model was subjected to environmental noise using triaxial velocimeter to identify the dynamic characteristics for each building model. Based on these tests results, it was found that the main frequencies of amplification of the structure, with the additional masses, up to 6 tones, are in the range between 5 and 10 Hz (see Figure 8).

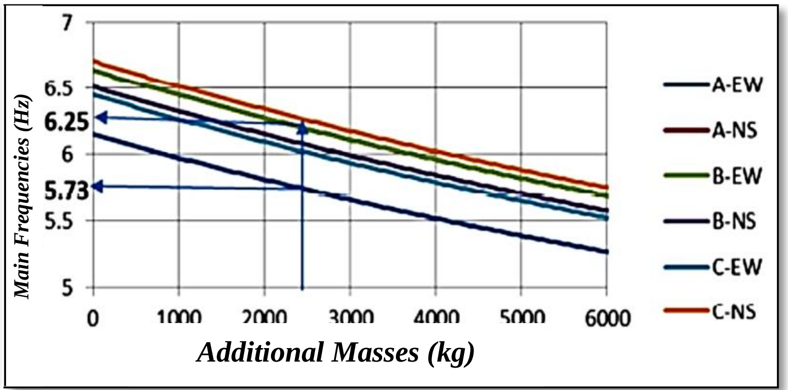


Figure (8): Estimate of Main Frequencies in E-W and N-S Directions vs. Additional Masses for the Three Model Buildings (A, B, and C)
[Source: ENEA UTTMAT-QUAL Report RT_08-2015]

The three model buildings A, B and C (see Table 1) were subjected to dynamic evaluation tests using the ENEA 4.0 m X 4.0 m calibrated shake table system (see Figure 4 and Tables 2 and 3). The input seismic loading history was designed such that the maximum spectral acceleration were in the range of 5.0 to 10.0 Hz. With additional weights up to 10 tons, the critical frequencies ranged from 4.0 to 7.0 Hz. The models were subjected to several ground motion excitations mimicking some of the major earthquakes occurred in the past 40 years in Italy (e.g. Gilroy, Colfiorito, Mirandola, Aquila, and Pettino Tabas). In addition, the models were subjected to seismic protocols in accordance to the IEEE344-2013 *Standard for Seismic Qualification of Equipment for Nuclear Power Generating Stations*. Each seismic test was preceded and followed by a sequence of random tests in a frequency range of 0.5 to10.0 Hz. Figure (9) presents a sample of the seismic input that were used in the three tests.

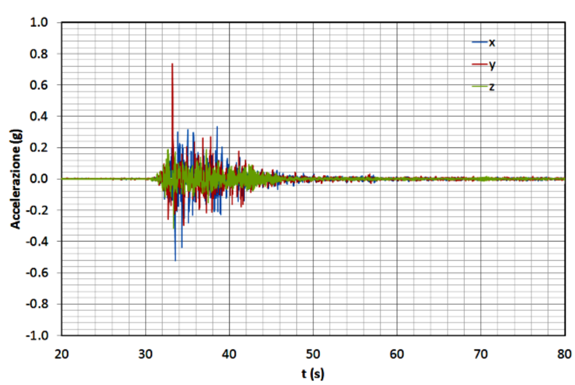


Figure (9): A Sample of Seismic Input used for the Three Model Buildings Tests
[Source: ENEA UTTMAT-QUAL Report RT_08-2015]

4.1 Drift and Lateral Displacements Results

The inter-story (or drift) of a building subjected to a ground is an important factor for determining the ductility and strength of any frame building. The inter-story drift is the difference in lateral deflection between two adjacent stories. The lateral deflection and drift can affect the lateral force resisting system members (*such as beams and columns*), elements that are not part of the lateral force resisting system (*such as the windows and cladding*), as well as the adjacent buildings. For this reason, all design codes imposes strict limits on such drifts including paragraph 7.3.7.2 NTC-2008 and section 12.12.1.1 of the American Society of Civil Engineers—ASCE 7: *Minimum Design Loads for Buildings and Other Structures* (ASCE 7), as well as the National Earthquake Hazards Reduction Program (NEHRP). These limitations are established in different codes not for serviceability reasons only, but due to its inherent effect of current seismic design provisions that is required to be checked to ensure life safety.

Figures (10a) and (10b) present the inter-story drift between the ground (base) and the first level of Building Models "A" and "B" that were subjected to ENEA test sequence on the 4.0m X 4.0m shake table.

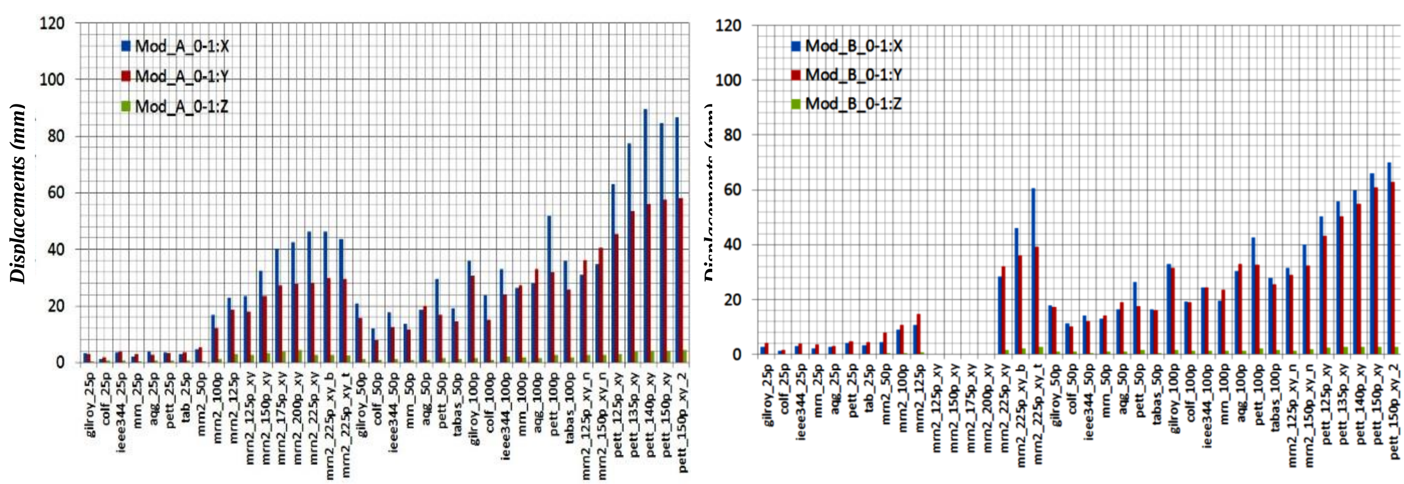


Figure (10): Inter-Story Drift between the Base (Ground) and First Level of ***(a)*** Model Buildings "A", ***(b)*** Model Building "B" with *Pillar Bone Core* System subjected ENEA Shake Table Test Sequence

[Source: ENEA UTTMAT-QUAL Report RT_08-2015]

The ENEA results for some of the sever simulated earthquake ground motions, showed that Model "B" with the Pillar Bone Core system exhibited on average a -5.95 % reduction in horizontal drift between the base (ground) and the first story level, and a reduction of -8.92 % between the first and second story of the model building as compared to Modal "A" without the Pillar Bone Core system.

4.2 Crack Development and Localized Damages

The results of tests indicated that both crack development and localized damage that occurred to the columns of Modal "A" (see Figure 11) were relatively severer that those observed for Model Building "B" with Pillar Bone Core system. These observations confirmed the results of previous tests that were conducted at CTM where columns with Pillar Bone Core system had a higher strength of about 37% as compared to those without the Pillar Bone Core system. In addition, less localized damages and permanent deformation were observed (refer to Figure 12). Similar confirmation based on the tests conducted at the University of Naples is presented in Figure (13), where a substantial strength and toughness enhancement were observed for column specimen "***B2***" with the Pillar Bone Core system as compared to the conventional column specimen "***A2***" without the Pillar Bone Core system.

Figure (11): Localized Damage and Crack Development Observed towards the End of the ENEA Shake Table Tests

Figure (12): Comparison between The Conventional (without core) and the Column Specimen with the Pillar Bone Core System

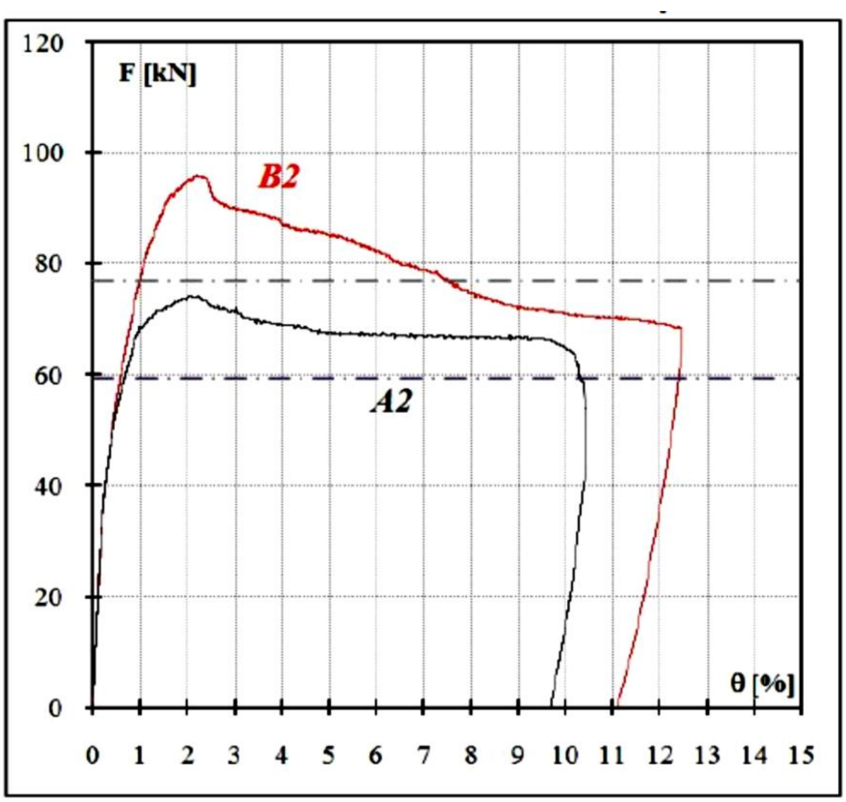


Figure (13): Large-Scale Experimental Results from University of Naples Shown the Higher Strength and Ductility of Column "***B2***" with the Pillar Bone Core System as Compared to the Conventional Column "***A2***"

5. CONCLUSIONS & RECOMMENDATIONS

In conclusions, the three experimental verification programs conducted on the Pillar Bone Core System developed by EDILINNOVA Ltd. for rehabilitation and upgrade seismic capacity of existing and new reinforced concrete columns have indicated the efficiency and reliability of this innovative system, not only for increasing the strength, but also in enhancing both the ductility and the inter-story drift of reinforced concrete column in particular and reinforced moment frame structures in general. Potential applications for this system include reinforced concrete bridge columns, piles and other critical structural elements.

It is recommended to have further confirmation tests at the University of California, Irvine in accordance to the requirements of the International Code Councils and the American codes and to establish design procedures for the system. Once verified, I believe that this system will offer the engineers and the public a more reliable construction system for both new and existing old buildings and structures.

6. REFERENCES

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