FULL SCALE TESTING OF POST TENSIONED MOMENT RESISTING CONNECTIONS OF A PRECAST CONCRETE STRUCTURE

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1 INTRODUCTION

Concrete prefabrication is a more practical and economical construction system compared to cast-in-situ reinforced concrete, due to its characteristics such as effective production planning, easy quality control, fast erection and improved aesthetics.

Furthermore, production of elements in covered areas eliminates the affect of adverse weather conditions, achieved by applying of steam or heat to concrete. Accelerated curing increase the speed of production. Additionally, prefabrication ensures significant timesavings in total construction durations, due to industrial fast production and as well as speedy erection.

Prefabricated structural elements are commonly produced "prestressed"; with prestressing forces applied during production. It is usually possible to cover larger spans with prestressed prefabricated structural elements compared to cast-in-situ reinforced concrete systems. Prestressed reinforced concrete elements offer economical alternatives to reinforced concrete elements for the same span. In addition, prestressed concrete is also highly superior to normal reinforced concrete in terms of crack control and limiting deflection.

In prefabricated systems industrially produced parts [i.e. vertical structural elements (columns) and horizontal structural elements (beams, girders)] are connected at a structural connection to form a load-bearing system. Therefore, connections of prefabricated concrete structures became a field of investigation as well as discussion, concurrently with the start of prefabricated production of concrete structural elements. Extensive research is conducted on this topic currently at research institutions throughout the world.

Column-beam connections in prefabricated concrete structures are classified as rigid (moment resisting), semi-rigid and hinged, in regards to its load transferring system. For multi-story buildings under horizontal loading such as wind and earthquake forces, moment resisting connections are preferred to form the load-bearing system. This requirement of moment resisting type joints for multi story structures subject to horizontal loading is emphasised in many national standards [1]. The two common types of moment resisting connections in prefabricated concrete structures are welded (dry) connections and cast-in-site (wet) connections.

A research program was initiated in 1999 YAPI MERKEZİ and METU, to develop a beam to column rigid (moment resisting) connection system. The objective was to improve on the performance of the two conventional methods described above, both in terms of strength, energy dissipation and quality assurance.

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The developed post-tensioned connection system utilises post-tensioning with high-strength steel cables to connect beams to the columns. The post-tensioned connection system was designed to be able to effectively transfer normal / shear forces and moments, and to have sufficient resistance and satisfying energy dissipation characteristics under seismic loading. In addition to the post-tensioning reinforcement, STIII grade mild steel was utilised to increase the energy dissipation capacity and to comply with the requirements of the TS3233 “Turkish Code for the Design and Construction of Prestressed Concrete Structures” [2].

2 MODEL LABORATORY EXPERIMENTS AND DEVELOPMENT OF THE SYSTEM

In cooperation with the Middle East Technical University Civil Engineering Department Building Mechanics Laboratory, a scaled test unit and a testing setup was developed to test the unbonded post-tensioned connection system. A monolithic wet-cast reference unit and 3 different (consecutively improved) prefabricated test units were designed, produced and tested under repeated reversible force exertion simulating seismic loading.

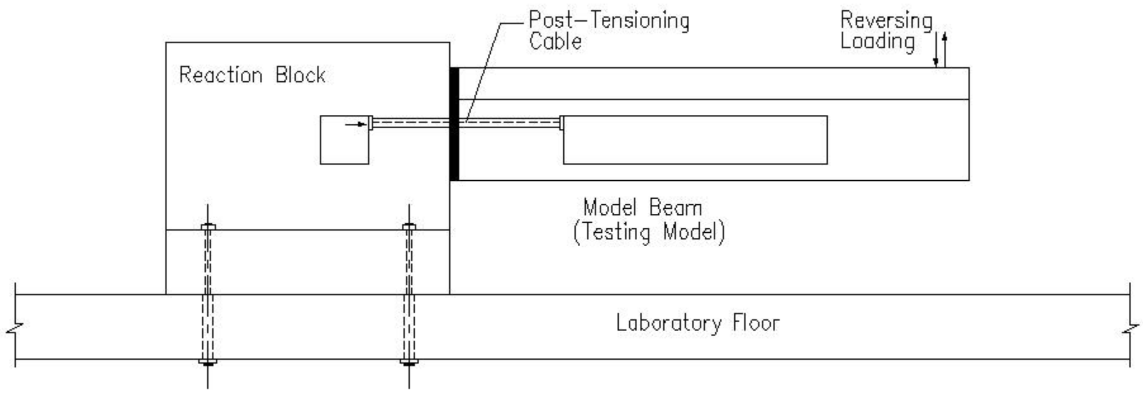


Figure-1: Test Unit on 1/ 2.5 Scale

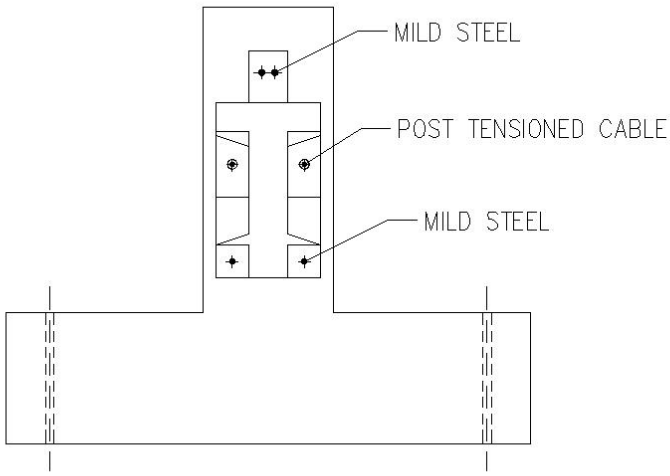


Figure-1a: Section

A paper was presented at this symposium by Dr. T. Tankut et.al. providing detailed information about the laboratory work done at M.E.T.U. [3]. During the experiments the connection system demonstrated superior load transfer capacity, and exhibited satisfactory seismic behaviour with significant energy dissipation properties. It is stated in the conclusion report issued by M.E.T.U. Faculty of Engineering; “We have reached the opinion that the unbonded post-tensioned connection pattern developed can be used in areas susceptible to earthquakes, provided that care is taken in its design and implementation”.

3 FULL SCALE TESTING

Following these successful lab-scale testing program carried out in cooperation with M.E.T.U., it was decided to construct a full-scale test building with post-tensioned connections in order to test, i) implementation procedures for these connections, ii) to verify laboratory test results on a building of real-life scale and iii) to develop confidence regarding the effectiveness of the new connection system. The loading tests were done in collaboration with Bosphorous University Kandilli Observatory Earthquake Engineering Department.

A two story, 2x2 bay typical prefabricated concrete moment frame was built for the full scale testing (Figures 2 thru 7). The bays are 6.45 m. in one direction and 6.00 m in the other. The top elevation of the first floor is +4.45 m., while the bottom clearance of the double inclination roof girders is +7.35 m. The columns in the two outside axis supporting the roof girders are 50cm.x50cm. The three remaining columns in the middle axis are 45cm.x45cm. The I-sectioned floor beams are 60 cm. in height and 40 cm. wide in the flanges. 20 cm. deep prestressed hollow core floor panels are used for the flooring system. The floor panels are covered with 5 cm topping concrete as required in seismic zones.

At the first floor level, the connection of the precast beam and column was constructed with unbounded post-tensioning cables located close to beam mid-depth.

During the implementation procedure demontable steel corbals were used. After post-tensioning these corbals were removed.

Following the completion of the building and the pouring of the topping concrete, the structure was loaded with 1000 kgf./m^2 distributed load and displacements in the joints were observed for a period of 30 days. The dynamic and static loading tests with horizontal loads were done with 600 kgf./m^2 distributed dead load.

3 hydraulic pistons, one with 50 tonf capacity and 2 with 75 tonf capacity each, were utilised for static horizontal force application. The pistons were located at the first story level. The force generated by the pistons located at the central axis was distributed to all three axis through a steel beam.

3.1 DYNAMIC TESTING PERFORMED TO DETERMINE THE NATURAL FREQUENCY OF THE STRUCTURE

Sudden Force Release System

In this test three steel balls and a guillotine mechanism was used to enable sudden release of the horizontal force applied. The purpose of the test was to measure the lowest natural frequency of the structure. The testing and instrumentation setup described below.

Figure-2: Full Scale Test Structure and Loading Setup

Figure-3: Full Scale Post-Tensioned Connection

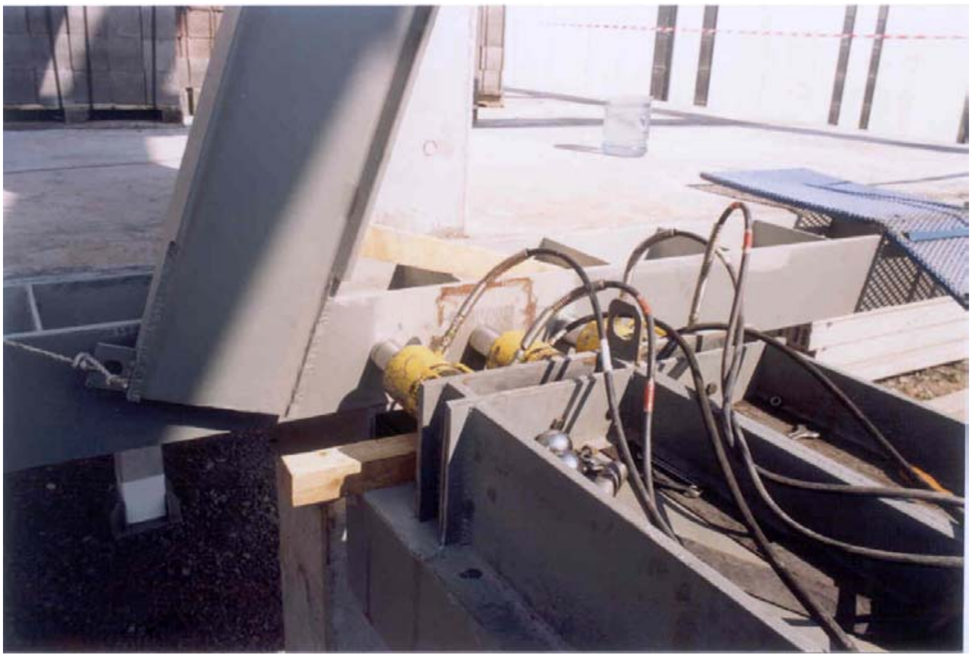


Figure-4: Full Scale Test Structure and Loading Setup

Figure-5: Full Scale Test Structure and Loading Setup

Figure-6: Full Scale Test Structure and Loading Setup:

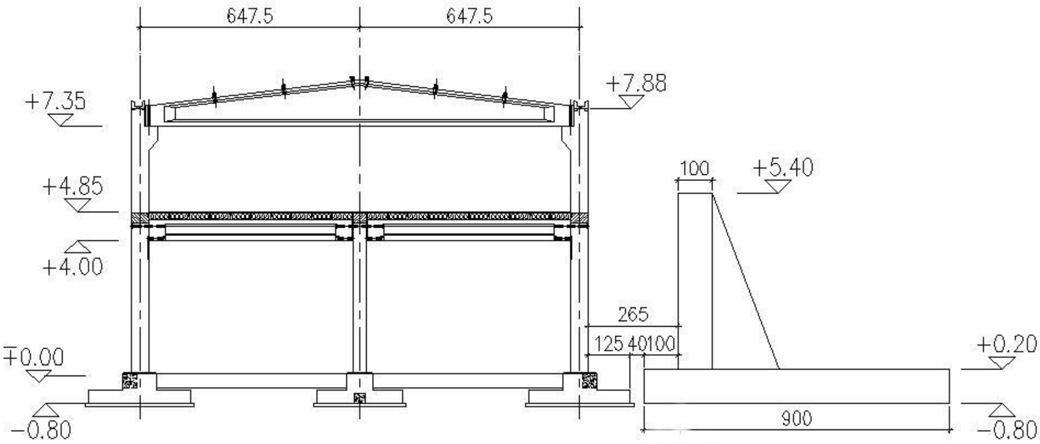


Figure-7: Full Scale Test Structure and Loading Setup:

Instrumentation System

Five unidirectional accelerometers and two three-directional accelerometers have been used to measure the acceleration, speed and displacement values at different levels of the building during the test. Figure 3 illustrates the position of sensors at each story. The devices used are as follows:

5 sensors (TML)	AM-2	(+,-) 1 g. range
2 accelerometers (GEOSYS)	GSR12/FB	With X,Y,Z directions
1 strain-meter (KENKYUJO)	SDA62B	

In the system established, GEOSYS accelerometers have been installed to take readings automatically (Figure 8). These accelerometers record two horizontal and one vertical readings simultaneously. TML accelerometers, on the other hand, are connected first to a strain-meter, then to on analogous/ digital (A/D) converter converting analogous readings into digital. The readings were stored to a laptop computer.

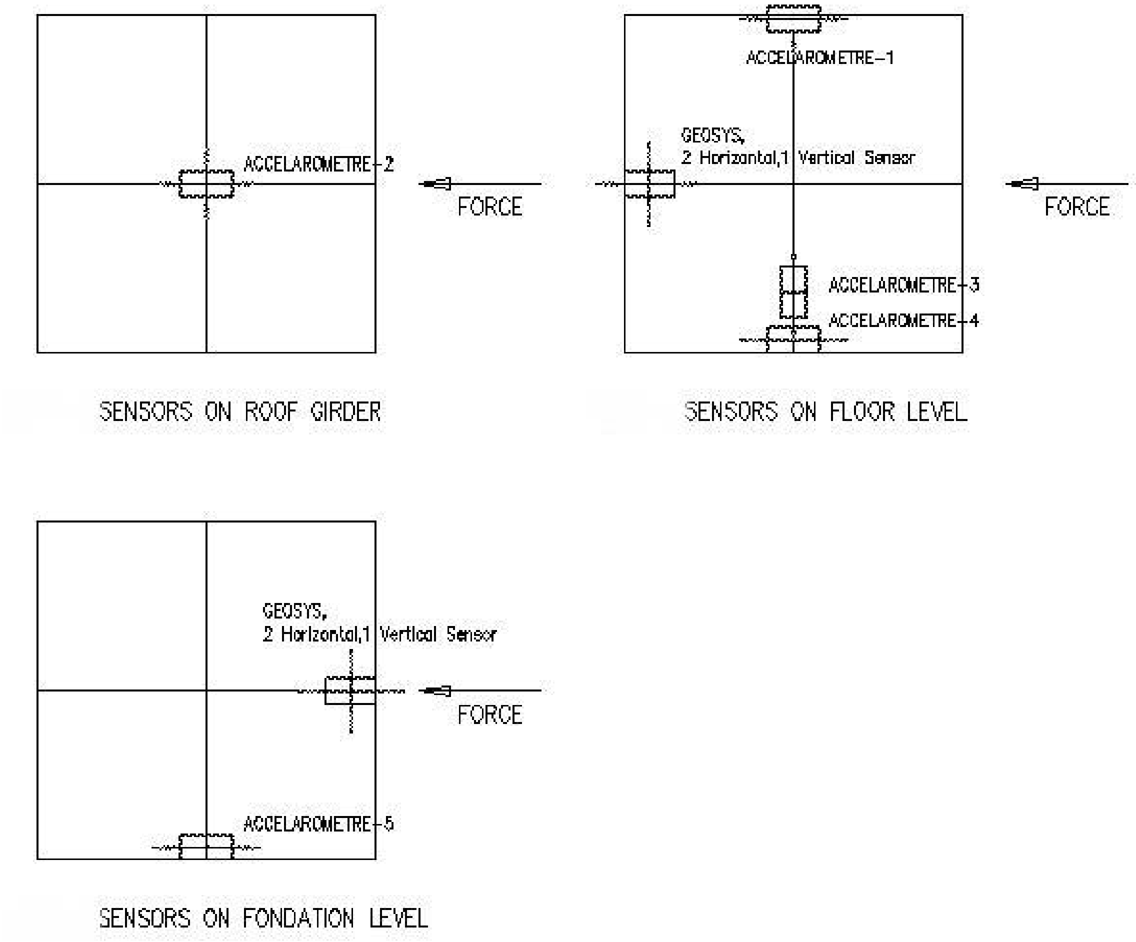


Figure-8: Sensor Locations

3.2 STATIC TESTING TO DETERMINE ELASTIC-PLASTIC BEHAVIOR OF THE STRUCTURE UNDER EQUIVALENT SEISMIC LOADING

The objective of these tests was to observe the elastic-plastic load-deformation behaviour of the structure. The structure was loaded with equivalent horizontal static loads applied at the first story level (Figure 4). An applied lateral load of 50 tonf was calculated to generate the same lateral displacement as the maximum elastic (reduced) base shear force (35.17 tonf) prescribed by the Turkish Seismic Code.

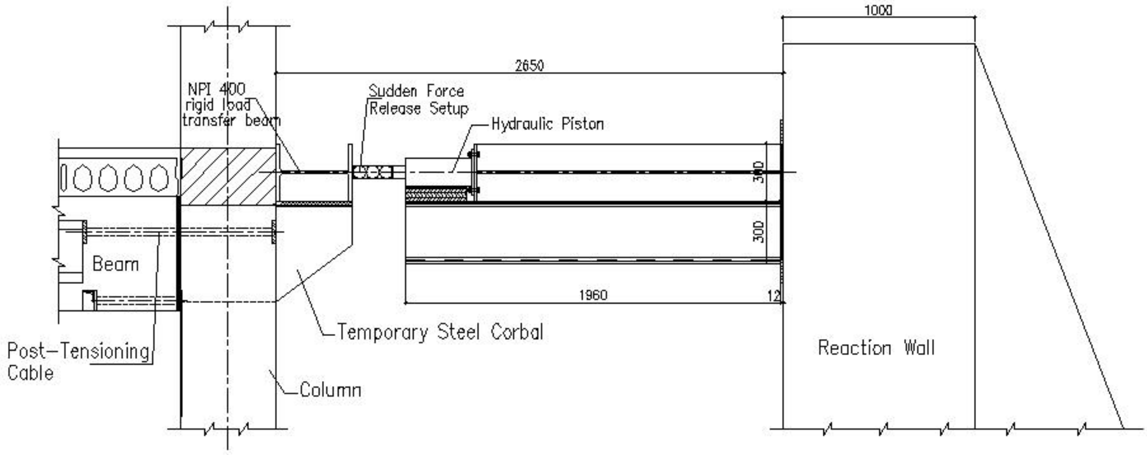


Figure-9: Lateral Load Application Detail

To emulate the lateral inertial loads generated by seismic excitation, static lateral loads were applied to the structure at the floor level. Equivalent static loads (generated by pistons) were calculated to create the same lateral displacements at the first floor level as the calculated static equivalent seismic base shear loads Figure 10.

Applied lateral loads were increased beyond the elastic design limit of the structure to observe the structural behaviour (deflections etc.) and the cracking patterns as plastic deformations formed. During these tests the structure was subjected to 150 tonf lateral load which was 4.27 times the reduced elastic design loads (4.27/R=85 % of the maximum equivalent seismic base shear load) which the structure would be subjected to during the maximum design earthquake forces (calculated according to the Turkish National Codes for Seismic Zone 1).

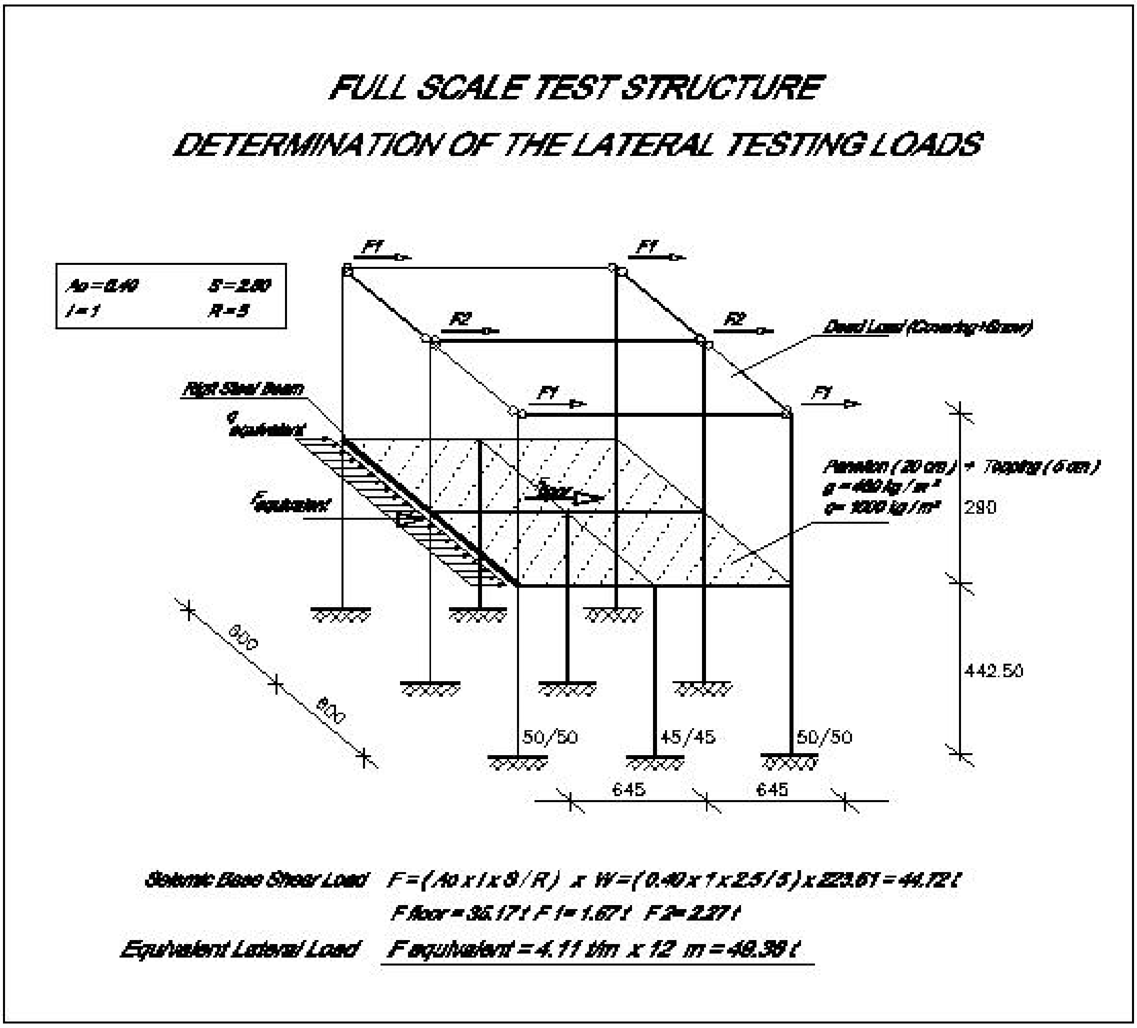
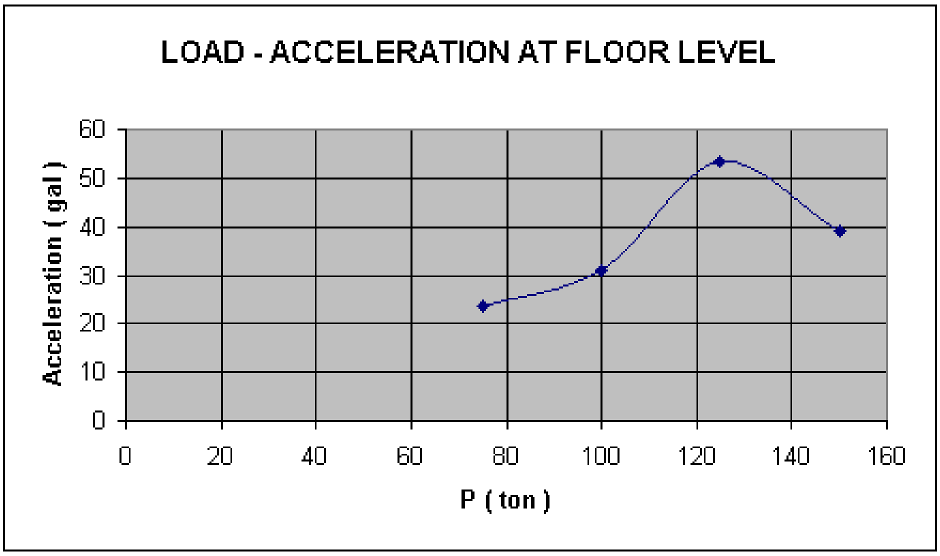


Figure-10: Static Lateral Loads Applied for the Tests

A sharp decrease in structural accelerations was observed beyond 125 tonf. This is due to yielding in the structure. As the structure yields the structural system becomes “softer” and the vibration periods increase accordingly. The decrease in the observed accelerations is a result of the increased vibration period. The lateral yield load observed was approximately twice the calculated yield load of 50 tonf. This is an expected result due to material safety coefficients and structural redundancy.

LOAD (ton)	Lateral DISPLACEMENT (cm)	VIBRATION FREQUENCY (Hz)	VIBRATION DAMPING (%)
10	0.044	4.14	0.84
50	0.310	3.99	1.52
150	1.800	3.5	7.00

Figure-11: Results of Lateral Loading Tests



P	acc. (gal)
75	23.72
100	31
125	53.54
150	39

Figure-12: Acceleration Results of Lateral Loading Tests

4 CONCLUSION

The laboratory and field experimentation indicates that an effective lateral load-resisting frame is implementable utilising post-tensioned connections. It is possible to generate an effective lateral load resisting structural frame system with the post-tensioned beam-column connection system.

The connection system exhibits high hsyteretic energy damping properties.

The proposed connection system eliminates the necessity for corbels in precast columns, and thus provides aesthetically pleasing architectural solutions and increased overhead clearance. The usage of temporary corbels is necessary while the beam-column connection is assembled. These steel temporary devices are removed once the connection is able to fully resist loads.

The erection (implementation) process did not present any unforeseen difficulties.

Cracks not exceeding 2 mm were formed at the bottom ends of the columns at max. horizontal load exertion, however no cracks were observed at beam-column connections.

The lab scale tests indicate that; when the load exceeds a level sufficient to displace the joint between a precast beam and a column, the behaviour of the joint deviates from the original linear elastic behaviour. The behaviour at the joint interface becomes nonlineer due to large deformations, whereas the post-tensioning steel remains elastic. As a result, due to the elastically deformed unbounded post-tensioned cables the connection return to its initial position when forces are released to zero. This behaviour was also observed during lab scale and field-testing.

The elastic and post-elastic deflections of the structure, and the free vibration periods were measured using an automated instrumentation system. The measured (observed) magnitudes were consistent with the values obtained from computer model simulations (Figure 13).

METHOD	PERIOD (sec)	FLOOR DISPLACEMENT (cm)
ACCELERATION TO STATIC LOAD ANALYSIS	0.27	0.3414
DYNAMIC ANALYSIS	1.800	0.3252
50tonf HORIZONTAL LOAD TEST RESULTS	0.24	0.3100

The performance of post-tensioned connections as verified by the lab-scale and full scale testing programs indicates that this new type of connection can be readily utilised as an improved alternative to other moment resisting connection systems in areas susceptible to earthquakes.

Post-tensioned connections constitute a safer and more easily constructed system compared to conventional connection systems in use in the industry with high seismic performance. The connection system is fully compliant with the Turkish Seismic Code and Turkish Standard 3233. [2]

5 BIBLIOGRAPHY

[1]. *Afet Bölgelerinde Yapılacak Yapılar Hakkında Yönetmelik* ("Turkish Seismic Code, Specifications for Structures To Be Built in Disaster Zones"), Turkish Republic Ministry of Public Works and Housing, 1997, page 56

[2]. *TS 3233 Öngerilmeli Beton Yapıların Hesap ve Yapım Kuralları* ("Turkish Code for the Design and Construction of Prestressed Concrete Structures"), Turkish Standards Institute, 1979

[3]. T. Tankut, U. Ersoy, S. Pınarbaşı, E. Arıoğlu, E. Özdil, M. Yorulmaz, "Tests on a Post Tensioned Moment Resisting Connection for Precast Concrete Structures", *Proceedings of the 17th B.I.B.M. Congress*, 1-4 May 2002