STRENGTHENING METHOD AND RELIABILITY TESTING OF PRECAST CONCRETE STRUCTURES

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Abstract

In 2012 Indonesia revised its seismic code, previously based on UBC 1997 to be based on ASCE 7-10. This revision indicates that existing building structures do not meet requirements stipulated in the new code. The UBC 1997 code allows intermediate reinforced concrete moment frame (IMRF) to be applied in moderate seismic area, but according to ASCE 7-10, this is no longer aplicable to sesimic design category D and E. Instead, ASCE 7-10 stipulates the use of special reinforced concrete moment frame (SMRF) for sesimic design category D and E. One strategy that can be adopted to make buidings originally design as IMRF meet the new code is to strengthen the joints by using additional ductile components, such that the structure mimic SMRF behavior. Joint strengthening using steel jacketing has been implemented in some existing precast concrete structural systems in Indonesia, primarily in the period of 2012-2015. Reliability of the buildings strengthened as such, has been commenced by performing tests with respect to gravity loading and tests with respect to lateral stiffness by microtremor testing. The test results demonstrated the success and effectiveness of the strengthening method in improving seismic resistance of existing buildings.

Keywords: IMRF,SMRF, steel jacketing, gravity testing, microtremor testing;

1. Intoroduction

The behaviour and the capacity of precast structural system to resist earthquake primarily depend on the detailing of structural joints. Factors determining the earthquake resistance capacity consist of type and quality of the materials used, implementation method and joint detailing. Each joint of precast system must be subjected to earthquake test, and the test results must indicate that the joint meets strength, performance, and acceptance criteria stipulated in the code.

Joints of newly design buildings can be construed so as to satisfy the requirements stipulated in the new code, but this is not the case with joints of existing structures [3]. The joints need to be strengthened to meet new requirements [2]. In other words, the buildings originally designed as IMRF based on UBC 1997 [4], need to be strengthened to behave as SMRF based on ASCE 7-10.

This paper deals with strengthening method of existing structural joints. The paper covers the description of joints of existing buildings, evaluation of the joint, repair and strengthening method, the testing of strengthening joints and the conclusion of the results.

2. Building Description

The building investigated was a nine-storey concrete precast system with its plan and perspective view being shown in Figure 1. Initial design of the structure was an open frame structure without shear wall. The structure consists of several mass buildings, among them were separated by dilatations.

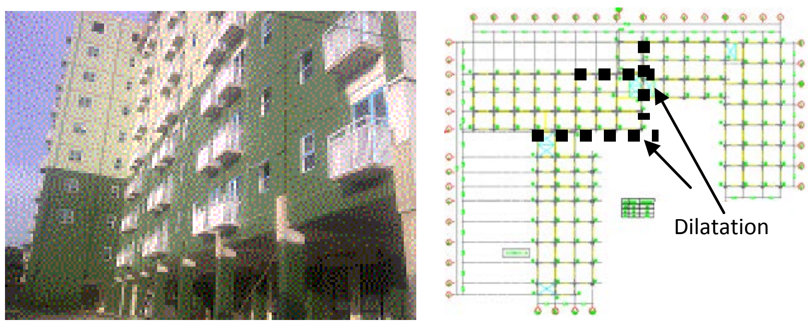


Figure. 1 – Building description

2.1 Detail of Precast System

The structure was made of precast concrete system, with joint detailing being shoen in Figure 2. Precast columns, beams and plates were used. The joints were of wet type of connection in which column reinforcing bars were connected in splice fashion in which the join was equiped with 3 hoop bars $\phi 6$, beams with 1 hoop bar $\phi 6$. The joint was tested in 2009 at Institute of Human Settkement, Ministry of Public Works laboratory [5]. The corresponding certificate that awarded for the system is shown in Figure 2. Certificate states that the joint may be applied up to 10-storey buildings, rith ducility factor μ = 4.42 and load reduction factor R = 7.08 – 7.26 .

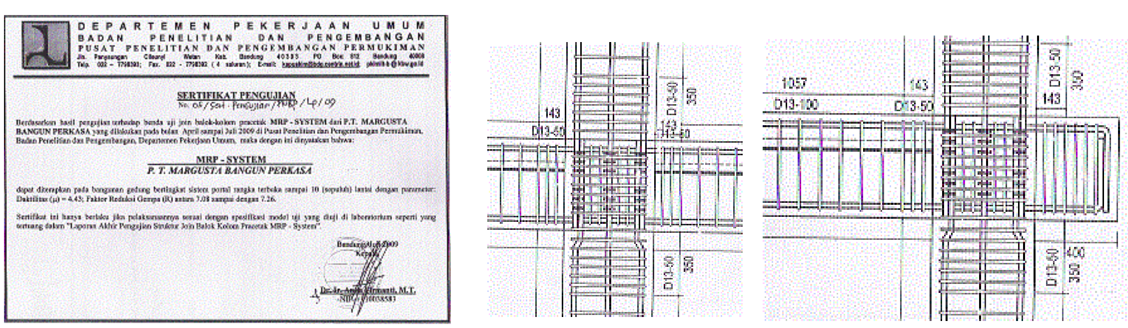


Figure. 2 – Joints of existing buildings

2.2 Evaluation of Existing Condition

The application of the precast system were observed at field, several findings, among others, are as follows.

1. The quality of concrete of columns and beams considered to be good. See Figure 3a.
2. The quality of concrete of plates is not good, cracks were found at some location as shown in Figure 3b.

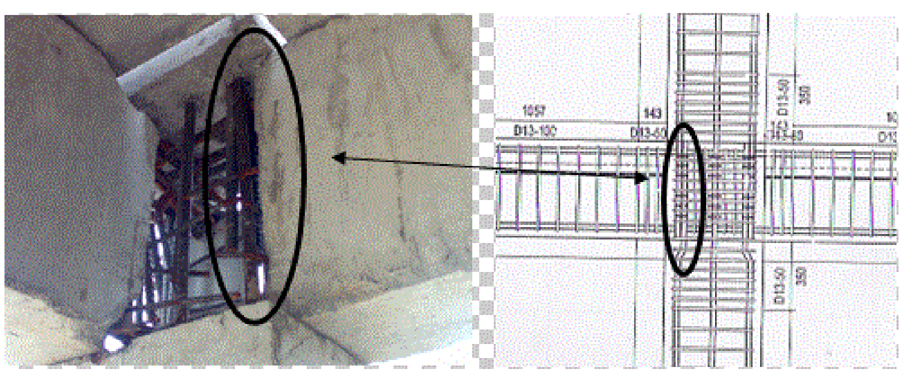
(a) (b)

Figure 3 – Condition of beam and column components

3. Precision of component dimensions was not god so that repositioning and edge cutting were necessary to be carried out to position the components at place. Damages and imperfection occured at joints as shon in Figure 4.

Figure. 4 –Precision of the components

4. Installation of the concrete precast system was generally not good, especially in the selection of appropriate equipments.
5. Joint detailing in the field deviated from that tested in the laboratory. Spliced column reinforcing bars should have covered all joint area, instead, the main column reinforcing bars were bent laterally as depicted in Figure 5. No ring binding bars were found.



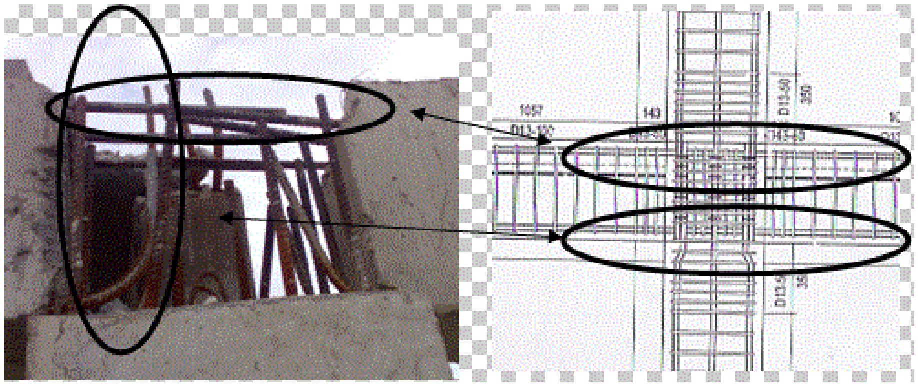


Figure 5 – Beam-column joint condition at field

6. Detail plate and beam connection does not represent rigid floor diaphragm as shown in Figure 6.

Figure 6 – Beam-slab joint condition at field

2.3 Method of Testing and Performance Evaluation

Based on site observation, it was concluded that the joint sstem was not in accordance with new specification, it was stipulated that the system might perform soft storey effect, and some evaluation on design performance needed to be carried out. Performance evaluations consists of several activities, starting from qualitative evaluation of building condition, selection in type and quality of materials used, evaluation of structural performance based on material testing, method of strengthening and repairment and testing of structural performance after strengthening and repairment. Flowchart of the performance evaluation is shown in Figure 7 .

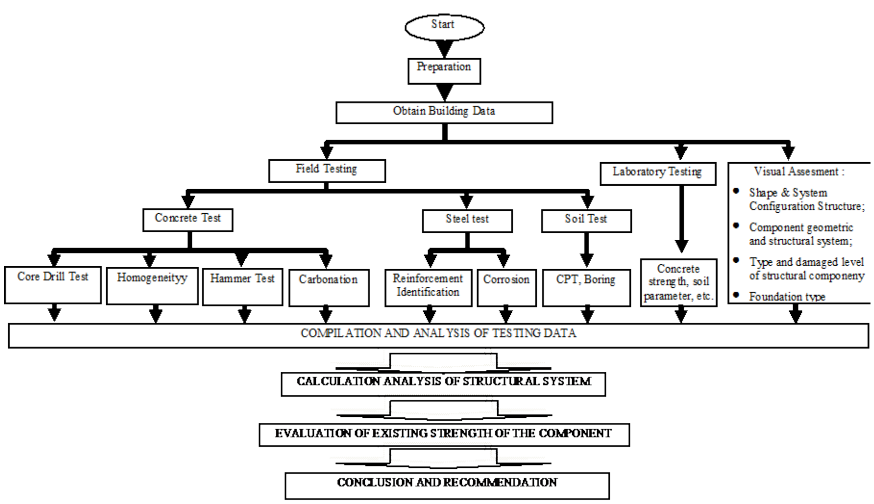


Figure. 7 – Flowchart oh the performance evaluation

2.4 Method of Repairing and Strengthening

Due to the findings that the detailing and the material used in the field differed from that specified, it was concluded that the repairing and strengthening of the joint had to be carried out. Joint strengthening was caried out by using ductile materials; in this case, steel jacketing, i.e., the use of steel plates that welded together so as to confine components. See Figure 8 as explanation. The gap between the plate and the component surface was filled with materials such as epoxy resin. The strengthening was carried out for joints within up to fourth floor, the rest (fifth floor up to roof) was made of new SMRS precast system.

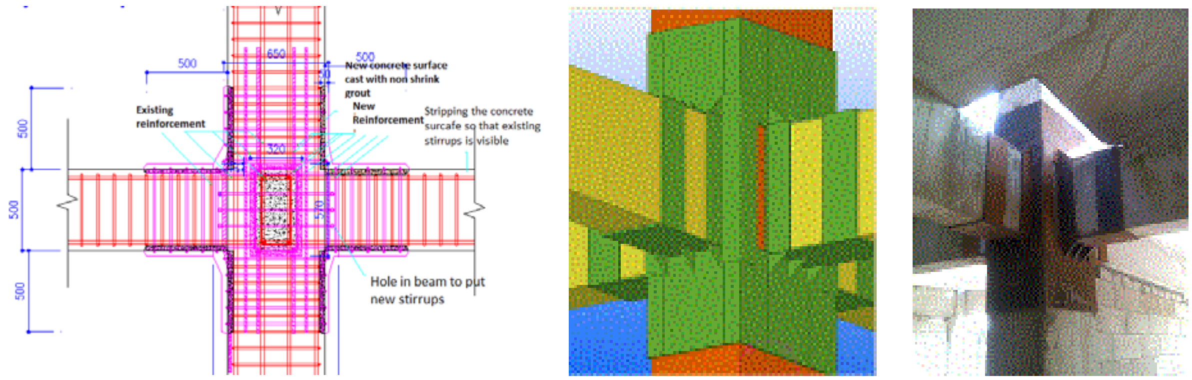


Figure 8 –Steel jacketing for joint strengthening

To prevent soft storey effect and to stiffen the structure, shear walls were added at locations from lower floor up to the second floor. The shear wall thickness was 30 cm. See Figure 9 for explanation.

Figure. 9 – Location and reinforcement of shear wall

The addition of shear wall requires the addition of foundations to withstand forces exerted at shear wall bases. Underpinning technique was used to place and construct the additional foundations. See Figure 10.

Figure 10 – Additional foundation at shear wall base

Additional reinforcing bars were provided to withstand negative moments at plate supports. Plates were replaced with newly designed components to limit deflection to the allowable limitation. See Figure 11.

Figure 11 – Extra reinforcement for floor slab

3. Testing Results

3.1 Material Testing

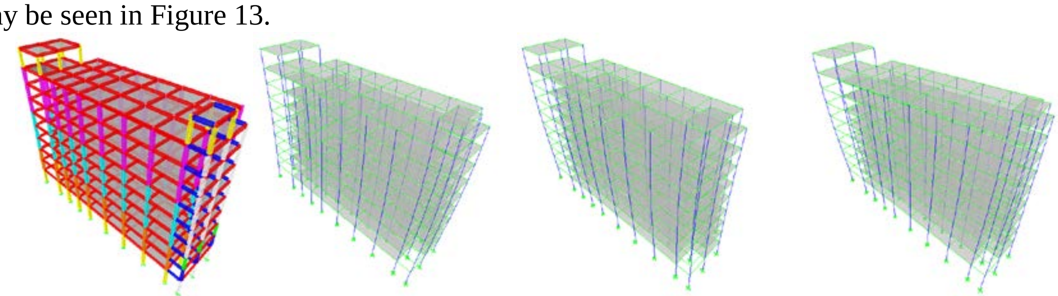
Material testing consisted of core drill test, Schmidt hammer test and Ultrasonic Pulse Velocity (UPV) test, as shown in Figure 12. The most worrying finding was that the core drill test showed that the concrete compression strength was only around 20 MPa, less than the specified value of 41 MPa. UPV test showed that the concrete was less uniform. Components tested were column, beam, and plate. The test results were used to evaluate the performance of the structural system.

(a) (b) (c)

Figure 12 – Material testing: (a) core drill, (b) Schmidt hammer, (c) Ultrasonic Pulse Velocity

3.2 Testing for Performance Evaluation

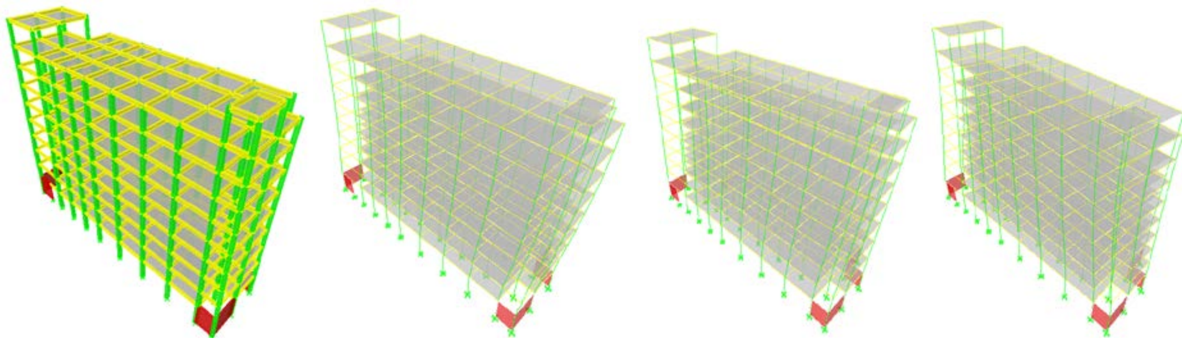
Structural dynamic analysis was carried out on the existing condition of structure using data obtained out of the testing. For example, in bloc A1, the compresion strength was fc' = 20 Mpa. The modes with corresponding time periods may be seen in Figure 13.



Model 3D MODE 1 (T = 1.3477) MODE 2 (T = 1.3014) MODE 3 (T = 1.2006)

Figure. 13 – Result of analysis of existing structure

Then, structural dynamic analysis was carried out on retrofitted structure using the same data as used in the analysis of existing condition fo structure. See Figure 14 for explanation. The load used was water gravity load to test the joint with respect to gravity load, and microtremor test to inspect structural reliability with respect to earthquake. Microtremor tests were conducted on the floor of individual structural building as shown in Figure 15.



Model 3D MODE 1 (T = 1.082) MODE 2 (T = 1.073) MODE 3 (T = 1.2006)

Figure 14 – Result of analysis of retrofotted structure

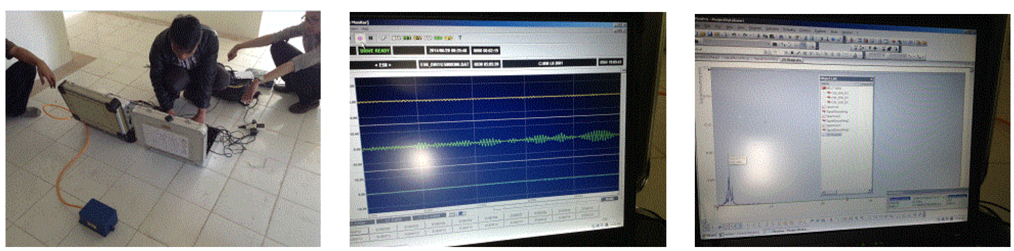


Figure. 15 –Microtremor test

The testing results in several findings as listed below.

1. Natural frequency of the structure in which first up to fourth floor were reinforced with steel jacketing, was f = 2.7 Hz (or T = 0,37 sec.)
2. Natural frequency of the structure in which first up to fourth floor were not reinforced with steel jacketing, was f = 2.3 Hz (or T = 0,43 sec.)

These results demonstrated that the reinforcement with steel jacket increased rigidity of the system. This indicates that the method of retrofitting of structural system is a success, the time period is less then obtained value from the analysis. Further model that including influence of steel jacketing on stiffness is under development.

Gravity loading test performed on a part of beam-slab strengthened by rigid floor diphragm is shown in Figure 16 [8]. Loading test was carrie out in accordance with Sections 20.3 up to 20.5 of ACI 318-08 [1]. The loading test level was 1.15 DL + 1.5 LL = 4.05 kN/m^2 applied as water. After reaching peak level, the load was then sustained for 24 hours, and then removed. The deflection were observed at all time of the testing.

Figure 16 – Gravity load testing

The load-displacement curve of the slab at transducer #4 can be seen at Figure 17. The maximum displacement is Δ = 0.31 mm, which meets requirement $\Delta_1 = lt^2 / (20000h)$ = 1.05 mm. The residual displacement Δ = 0.02 mm, which meets requirement $\Delta_r = \Delta_1 / 4$ = 0.07 mm.

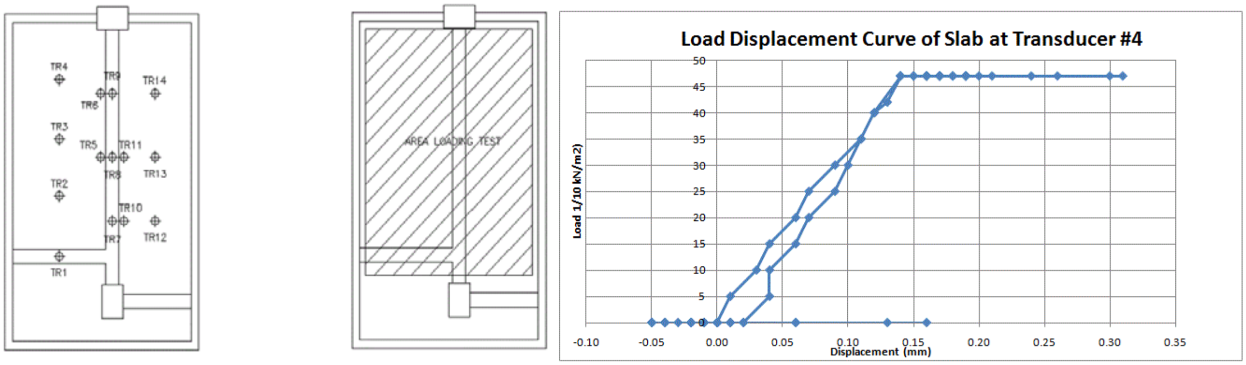


Figure. 17 – Load-displacement curve

4. Conclusions

Precast concrete systems have to be designed and constructed in accordance with the new code. The presence of deviation in existing building condition apart from new regulation, needs evaluation to inspect the reliability of the existing structures. Retrofitting and strengthening are necessary to make existing structure conformed to new code. Strengthening method proposed in this research may be applied to existing buildings originally design as IRMF based on UBC 97 [4], to become SMRF based on ASCE 7-10.

5. Acknowledgements

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6. Copyrights

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