Seismic Strengthening and Retrofitting of an Existing Overstressed RCC Structure Using Micro-concrete

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Abstract

Seismic Strengthening and retrofitting of an existing structure is a need-based concept aimed to improve the performance of any structure under future earthquakes. The need for the strengthening of structures arises due to preserve of historical, artistic, social and human links and also to comply with more recent code requirements. In this study, a nine storied reinforced cement concrete (RCC) industrial building was selected and assessed its seismic capacity through finite element method. The structural integrity assessment was performed by different destructive testing (DT) and non-destructive testing (NDT). It was found that twenty eight columns and six beams at different floors were overstressed. Analysis results revealed that the structure did not have sufficient structural capacity to resist even a moderate earthquake. High strength micro-concrete was used to enhance the strength of selected structure by the method of retrofitting. It was found that reinforced concrete (RC) jacketing (retrofitting) is the most effective and economic strengthening technique to remove the weak columns and not-safe column-beam joints in shear. After the analysis of cost, it was found that the strengthening of an existing damaged/overstressed RCC structure is more economical than the demolition and rebuilding.

Keywords: *RCC; Micro-Concrete; Strengthening; RC Jacketing; Structural Integrity.*

1 Introduction

Strengthening is an improvement over the original strength when the evaluation of the building indicates that the strength available before the damage was insufficient and restoration alone will not be adequate in future quakes. The seismic behavior of old existing buildings is affected by their original structural inadequacies, material degradation due to time, and alterations carried out during use over the years such as making new openings, addition of new parts inducing dissymmetry in plan and elevation, etc. (MHA Guideline, India, 2006). Some recently developed techniques can play vital role in structural repairs, seismic strengthening and retrofitting of existing buildings, whether damaged or undamaged. The primary concern of a structural engineer is to successfully restore the structures as quickly as possible. The most common types of jackets are steel jacket, reinforced concrete (RC) jacket, fibre reinforced polymer composite jacket, jacket with high tension materials like carbon fibre, glass fibre etc. (Waghmare, 2011). RC jacketing is the most popularly used method for strengthening of buildings. Structures under repair often require building up with high strength concrete (Yalciner and Hedayat, 2010). Conventional concrete poured in the jacketing shutters often exhibits honey combing and poor adhesion apart from its inability to effectively fill the recesses of the broken members and penetrate behind the reinforcements. Mortars used in this area of application have shown a poor strength and high degree of permeability and they can never match the strength properties of original concrete. Micro-Concrete forms an easy tool in the hands of Structural Repair Contractor to get over the major problem of making up the broken/damaged member with a high strength absolute waterproof and free flowing concrete which tends to flow in all directions to effectively fill and build up the member.

The possibility of substituting of old existing buildings with new earthquake resistant buildings is generally neglected due to historical, artistic, social and economic reasons (Sengupta, 2001). The complete replacement of the buildings in a given area will also lead to destroying a number of social and human links. Therefore seismic strengthening of existing damaged or undamaged buildings can be a definite requirement in same areas. The need for the strengthening of structures also arises in cases where existing structures must comply with more recent code requirements. Comparison of the design levels for seismic lateral loads between previous codes and the current loading code indicates that buildings designed to the previous codes often do not satisfy the strength and ductility requirements of the current loading code. Typical deficiencies of moment resisting frames are: inadequate shear strength of columns and beam-column joints and inadequate flexural strength and ductility of columns. Structures need repairing & strengthening in the case of Structural damages: Fire damage, Seismic damage and Blast damage, corrosion of reinforcement, insufficient reinforcement, chemical damage and excessive loads (Russell, 2015). The aims of this study are to increase the seismic capacity of the moment resisting framed structures, to strengthen a structure to satisfy the requirements of the current codes for seismic design, to restore or improve structural integrity, appearance, durability and functional performance (Soudki, 1999).

2 Materials and Methods

2.1 Micro-concrete

Micro Concrete is a flowable mortar that is used for re-strengthening of reinforced concrete members. It is supplied as a dry powder which requires only addition of clean water at site to produce a free flowing non shrink repair micro concrete. This is a cementitious material, with additives, which impart controlled expansion characteristics in the plastic state while minimizing water demand. This is specially designed for repairs to damaged reinforced concrete elements, particularly where area is restricted and where vibration of the placed material is difficult or impossible. Areas of application of micro concrete are the followings-

a) Repair to damaged reinforced concrete elements like beams, columns, wall etc., where access is restricted and compaction is not possible.
b) For Jacketing of RCC columns to increase load taking capacity (strengthening of a vertical member).

2.2 Jacketing Techniques

Reinforced Concrete jacketing (Section Enlargement) means the placement of additional concrete and reinforcing steel on an existing structural member. Beams, slabs, columns, and walls, if necessary, can be enlarged (Retrofitted) to add stiffness or load-carrying capacity. In most cases, the enlargement must be bonded to the existing concrete to create a monolithic member for additional shear or flexural capacity. Jacketing restores the section of an existing member by encasement in a new concrete (Jagtap and Mehetre, 2015). This technique is applicable for protecting the member against further deterioration as well as for strengthening. Strengthening of existing structures is needed when –

a) Load carried by the column is increased due to either increasing the number of floors or due to mistakes in the design.
b) The compressive strength of the concrete or the percentage and type of the reinforcement is not according to the codes requirement.

2.3 Seismic Loadings

Scientific geological study of the earth crust below Bangladesh shows that Bangladesh does fall in moderate to high seismic risk zone. Statistical evidence from past major and minor earthquake incidents shows that a major earthquake is overdue in the recent times of geological scale. Therefore, it is necessary to prepare against any possible earthquake hazard. It should be kept in mind that the objective of earthquake resistance building design is not to make a strong building which can resist any damage due to earthquake. Instead, earthquake resistant design basically aims at minimizing the possible damage and casualty to an acceptable level (BNBC, 2006). For the analysis and design checking of this building, Equivalent Static Force Method of Bangladesh National Building Code-2006 (BNBC-2006) was followed. The step by step approaches for **Strengthening (RC Jacketing) Procedures** (CPWD Manual, 2002) are given as follows:

2.4 Supports

The RC members were properly supported before chipping the old spilled/loose concrete. Adequate props were provided to give sufficient structural support to the load carrying members.

2.5 Preparation of Concrete Surface

After providing props, the column surface was grinded by grinding machine to remove pre-applied mortar plaster, oil, paint, grease, waterproof coating, etc. carefully. Then column surface was cleaned by blower machine to make the surface dust free. Thus the column was prepared properly for rebar anchoring.

2.6 Provision of Additional Reinforcement

Additional reinforcement required for strengthening of RC members was provided as per the design (Figure 1). The additional reinforcement have been properly anchored to the existing concrete by providing adequate shear connectors.

Figure 1. Additional Reinforcement Provided for Strengthening.

2.7 Provision of Shear Connectors

Shear connectors of 10 mm diameter were provided in holes of 16 mm diameter and 100 mm deep. These were provided at every 300 mm c/c on all the faces of the beams in staggered form. The holes were cleaned with compressed air to remove all the dust. Then the shear connectors had been fixed in the holes using Chemical Lock-fix (Master Flow 935 AN).

2.8 Application of Epoxy Bonding Agent

After rebar binding, existing concrete surface was wetted by pouring water. Then the epoxy bonding agent was applied on old concrete surface (Figure 2) by paint brush after water soaked by concrete covering the area where concrete casting was going to be taken place. After providing bonding agent within 6 hours concrete casting was completed as per concrete design. Proper compaction in concrete casting has to be ensured with vibrator.

Figure 2. Application of Epoxy Bonding Agent.

2.9 Formwork and Shuttering

After the application of bonding agent, slurry tight and strong form work was prepared (Figure 3). Then the shutter oil (Reebol) was provided in inner sides of shutter so that shutter can be removed easily. Every 3 meters column jacketing was done by two steps for proper compaction. After completion of concrete casting the shutter was checked properly to avoid any leakage and 3 days (72 hours) after casting shutter was removed.

Figure 3. Shuttering adjustment.

2.10 Mixing of Micro Concrete

The mixing of micro concrete was done mechanically using the appropriate water powder ratio. Mixing was carried out for 3 to 5 minutes to ensure homogeneous mix without any bleeding or segregation. In hot climate ice cooled water shall be used to maintain the temperature of mixed material. If the encasing thickness is more than 100 mm, stone aggregates up to 50 % by weight of micro concrete may be added to the mixed micro concrete directly into the mixer hopper. The stone aggregates must be 12 mm and shall be clean, washed and dried.

2.11 Pouring of Micro Concrete

A suitable hopper/funnel arrangement was made at site to facilitate the pouring of micro concrete into the formwork. The pouring operation was done continuously unless the job had been completed (Figure 4). To achieve this sufficient mixers, drilling machines and work force was arranged at site.

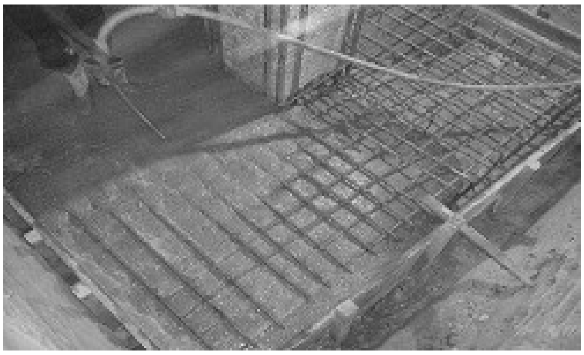

Figure 4. Pouring of Micro Concrete.

2.12 Curing

After completion of concrete casting and de-shuttering the casted concrete was washed with water properly. Then whole surface of new concrete was covered with two layers of curing compound agent by paint brush.

3 Results and Discussion

Structural integrity assessment was performed and remodeled the structure using powerful finite element based structural design software package CSI Etabs V15.2.0 and CSI Safe V14.1.1. The adequacy of footings (size & thickness), columns, beams and grade-beams were also checked and analyzed after rectification. The seismic strengthening of the existing overstressed/inadequate RC members was performed by RC jacketing using free flowing micro-concrete.

The Figure 5 indicates the column P-M-M interaction ratios. The column P-M-M interaction ratios less than one is adequate. After rectification, it was found that all of the columns were adequate in shear and flexural capacity.

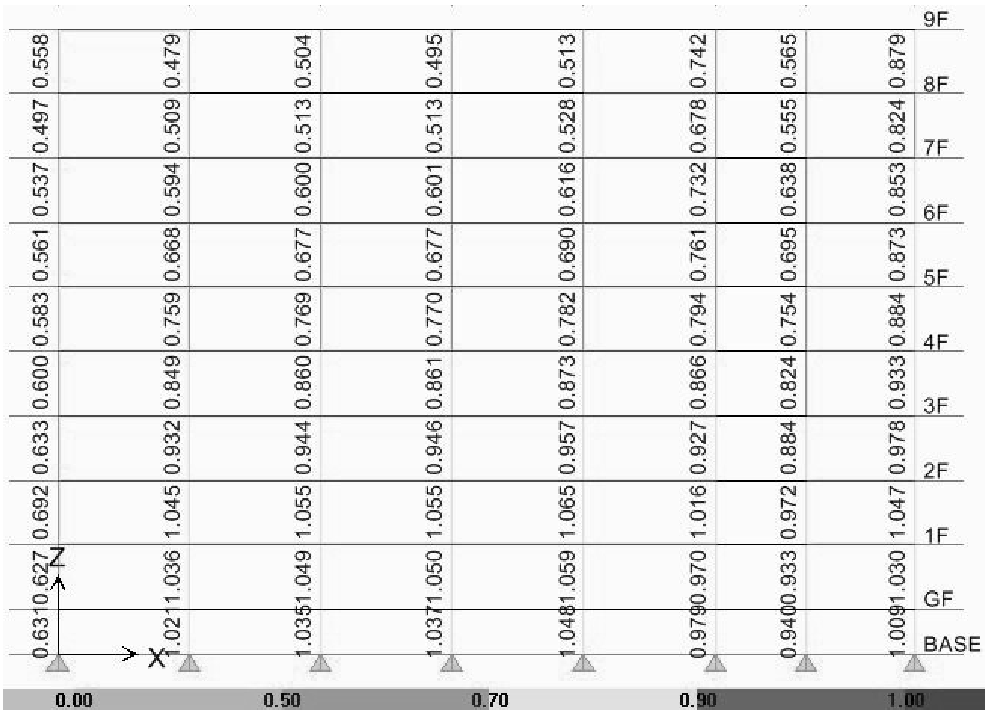

Figure 5. Checking Adequacy of Column after Rectification.

The Figure 6 indicates required reinforcement of beams. After rectification, it was found that all of the grade beams and floor beams were adequate in shear and flexural capacity.

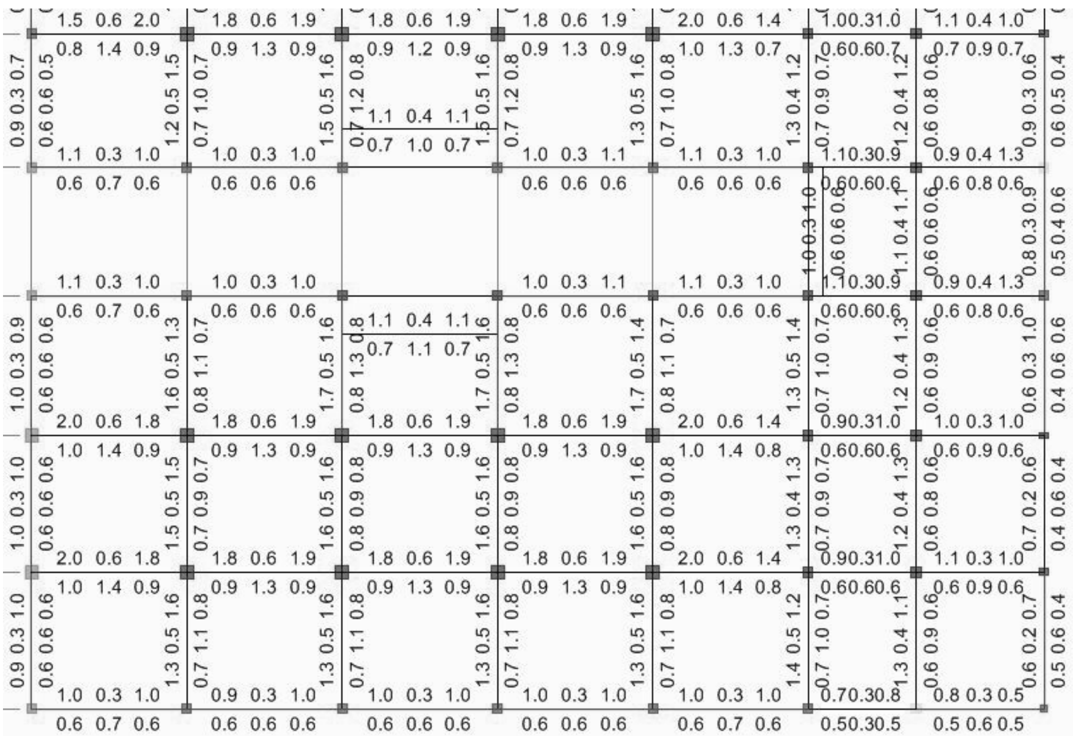

Figure 6. Checking Adequacy of Beam after Rectification.

All of the footings were also adequate in size (in respect of soil bearing capacity) and in thickness (for punching shear). Thus, the vulnerability of damage of an existing overstressed/damaged structure during a future earthquake has been reduced (by satisfying the requirements of the current codes for seismic design) by the method of retrofitting using micro-concrete.

4 Conclusions

Based on the above results and application, Retrofitting (using free flowing, self- leveling, self-compacting and high early strength micro-concrete) is the most effective and popularly used technique for structural strengthening. The benefits of retrofitting include the reduction in the loss of lives and damage of the essential facilities, and functional continuity of the life line structures. Retrofitting also raises the level of performance of life line structures in earthquakes. This method provides better solution for avoiding buckling problem, if the column in building is found to be slender. The resulting cured member not only strengthens the reinforced concrete member but also acts as an excellent barrier to the corrosion agents, which are detrimental to concrete and the reinforcement. For an existing structure of good condition, the cost of retrofitting tends to be smaller than the replacement cost. This seismic upgrade methodology proved to be technically sound, easy to execute, less disruptive to the occupants and resulted in significant savings both in terms of time and cost. Thus, the retrofitting of structures is an essential component of long term disaster mitigation.

This work can be further extended to (a) Strengthening of the existing structure with different retrofitting techniques (b) Study on the performance of the existing structure after retrofitting (c) Study can be done by increasing the additional floors on existing structure and requirement of strengthening for that.

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