Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.VII)

12-4-2

RETROFITTING OF EXISTING BUILDINGS AGAINST SEVERE EARTHQUAKES

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SUMMARY

Many buildings in urban conglomerations lying in active seismic zones have primary structural systems that do not satisfy current seismic code requirements. Such buildings are susceptible to damage in a future earthquake. The success of an economical retrofitting program depends on the judicious selection of a method coupled with the available construction material and techniques. This paper presents a case study of retrofitting of an existing R.C. frame building considering different techniques and the cost economics of these methods. Strengthening of end portions of deficient members turns out to be the most economical method of retrofitting.

INTRODUCTION

Retrofitting of existing reinforced concrete building can be described as backing up existing structure in order to increase its seismic force resistance level so that it can safely withstand future strong earthquake. The design of a building is governed by the then current state-of-the-art of engineering. The response of an existing building to a strong ground motion is an indication of performance level inherent in the codes, standards and construction practices in existence at the time of design and construction. The design criteria and judgement regarding the safety of the building quite often change from the analysis and judgement of the engineer during the original design process. As a result the margin of safety of an existing building may also change from that assumed at the time of design. There are many buildings that have primary structural system which do not meet the current seismic code requirements. The need therefore exists to evaluate and retrofit such buildings to mitigate unacceptable hazards. The retrofitting of existing buildings may become a necessity under following situations,

(i) Upgrading of a seismic zone
(ii) Modifications/alterations in existing building
(iii) Upgrading of design codes
(iv) In the event of prediction of a severe earthquake in nearby fault.
(v) If a type of buildings have shown to be vulnerable in recent earthquakes
(vi) Buildings in which earthquake resistance is deteriorated due to various reasons

This paper presents a case study of retrofitting of an existing building with the following objectives:

(i) To evaluate the response of primary structural system of a building when subjected to the normal vertical loads and earthquake forces and to locate the structural deficiencies of frame members.

(ii) To increase the seismic resistance level of the primary structural system through various strengthening techniques and to work out their cost economics.

A CASE STUDY

Reinforced Concrete Building: The case study concerns with an existing thirty six - storeyed reinforced concrete building. Figures 1 and 2 respectively show the plan of tower block and the frame work along grid 10. The tower block is separated from the side frame which rises upto seventh floor level, by an expansion joint. The primary structural system consists of reinforced concrete moment resisting frames and unreinforced masonry filler walls. There are no shear walls or core in the building. The concrete used has minimum 26.5 and maximum 44.0 N/mm^2 cube strength. The members of the frame particularly the tower block are heavily reinforced with high yield strength deformed bars.

Method of analysis: The building is first statically analysed as a plane frame for combination of dead, live and wind loads. To check the performance level of resistance of the primary structural system against severe earthquake forces, dynamic analysis has been carried out for Koyna earthquake of Dec. 11, 1967 which had occurred in the region. The main assumptions in the analysis are the following:

(i) The building is considered to be linearly elastic

(ii) The soil-structure interaction effect is neglected

(iii) The effect of infill walls on the stiffness of the frame is neglected

(iv) The axial deformation is considered in all members in addition to bending and shear deformation

(v) The mode superposition method with root sum of square method of combining modes is employed for dynamic analysis

Load Combination: The following load combinations have been used as per current IS Code (Ref. 1) for checking the design of existing building,

Static Case - 1.2(Dead load + Live load + Wind load) (1)

Dynamic Case- 1.2(Dead load + 0.25 Live load + Earthquake Load) (2)

Basis of strength evaluation: The collapse criteria and capacity ratio concept has been adopted for evaluating frame members that are structurally deficient. The capacity ratio (C.R.) is mathematically described below:

$$C.R. = C/R \tag{3}$$

where, C = Capacity of member to resist forces (moment, shear and axial), obtained on the basis of cross-sectional properties of member, and R = resulting member forces obtained from critical load combination. The capacity ratio less than unity implies that the member is structurally deficient and needs strengthening.

Results: The building was originally designed for seismic Zone I of IS Code (Ref. 2). The analysis has shown that the building is safe for even Zone IV and Zone V of the Code. However, when the structure is analysed for the actual Koyna Earthquake (Dec. 11, 1967), certain members are found to be structurally deficient with respect to moment only. The column 2 of Table 1 shows the capacity ratios of some of existing structure elements for which the values are less than unity. The members found to be structurally deficient are shown in Fig. 2.

RETROFITTING OF BUILDING

There can be various methods of retrofitting depending upon reasons of retrofitting, type and condition of member and the structure. The seismic force resistance level of a structural system can be basically increased by the following procedures;

(i) Addition of new systems to an existing structure.
(ii) Strengthening of individual members and connections.

The retrofitting by adding new systems such as braces, shearwalls etc, is often employed. This method positively alters the dynamic characteristics of the building and also the structural behaviour. Here the second procedure is adopted for retrofitting (Ref.3). The main merit of this method is that the original structural system is maintained. In order to improve moment capacity of deficient members, the following retrofitting techniques are employed:

Casing: The section is cased from all the four sides with new concrete and reinforcement in order to increase its moment of resistance.

Jacketing: The beam is enclosed from three sides with new concrete and reinforcement. The method is suitable for retrofitting under reinforced beams.

Building up: In this method either one or two sides of deficient beam or column is built up with new concrete and reinforcement.

Strengthening end Connection: In this method the end sections of structurally deficient beams and columns are reinforced by removing the existing cover and welding extra reinforcement and then grouting the section. The extra reinforcement is provided for a distance of one fifth of span from either ends.

Retrofitting Combination: In the present case study the following combinations of retrofitting techniques are tried :

Case I Casing of beams as well as columns (Figure 3)
Case II Jacketing of beams and building up columns from two sides (Figure 4)
Case III Building-up of beams and columns from two sides (Figure 5)
Case IV Building-up of beams and columns from one side (Figure 6)
Case V Strengthening of end portions of beams and columns (Figure 7)

Reanalysis of retrofit structure: Reanalysis for each of the cases considered is carried out to check the safety of structures. Table 1 shows the capacity ratio for different cases, which clearly shows that after retrofitting it is greater than unity in the earlier deficient members. Fig. 8 shows that the total shear in modified structure is increased as compared to original structure. The dynamic analysis of retrofit structure indicates that the modified structure shows adequate behaviour.

Expansion Joint: The details of existing expansion joint is shown in Figure 9. The dynamic analysis indicates that at the joint the net displacement between tower block and side frame exceeds the existing gap of 25mm. Thus hammering can occur at the joint during a severe earthquake. In order to avoid hammering, the expansion joint detail need to be modified to accommodate expected displacement. The end portion of the slabs meeting at expansion joint should be cut by 19mm. The recommended modification of expansion joint detail is shown in Fig. 10.

COST ECONOMICS

In order to arrive at a cost-effective scheme, the costs in the five cases of retrofitting are worked out. These include, the cost of material, labour, and equipment. Table 1 also shows the cost of retrofitting in five cases expressed in Rupees per square meter of total floor area. It is clear from this table that the cost of retrofitting works out to be minimum for Case V, while it is maximum for Case I. In Case V, retrofitting has been achieved by modifying the section properties at the joints only. This method leads to considerable saving of concrete and steel.

CONCLUSIONS

The following conclusions can be derived from this study:

1. Some members at higher levels showed structural deficiencies in a possible future severe earthquake. The deficiency is mostly observed in beams.

2. The reanalysis of retrofitted structures shows hammering at the expansion joint. A modified detailing of expansion joint is proposed which consists of creating additional gap by cutting the adjoining slabs by 19mm.

3. The most economical methods of retrofitting in the case study is found to be the modification of end sections of structurally deficient members, that is, Case V, Fig.7.

REFERENCES

1. 'IS: 456-1978 Code of Practice For Plain and reinforced Concrete', Bureau of Indian Standards, New Delhi 1981.

2. 'IS: 1893-1975 Criteria for Earthquake Resistant Design of Structures', Bureau of Indian Standards, New Delhi 1976.

3. Mokha, A.S. 'Retrofitting of Existing Reinforced Concrete Buildings Against Severe Earthquake Forces', M.E. Thesis, University of Roorkee, Roorkee, Feb. 1985.

TABLE - 1

CAPACITY RATIO OF EXISTING AND RETROFITTED STRUCTURE AND COSTS OF RETROFITTING

Member Type	C.R. of Existing Structure	C.R. of Retrofitted Structure				
		Case I	Case II	Case III	Case IV	Case V
B-1	0.85	1.15	1.09	1.18	1.06	1.07
B-1	0.91	1.12	1.17	1.18	1.12	1.23
B-2B	0.70	1.10	1.13	1.13	1.29	1.06
C-1A	0.91	1.11	1.09	1.11	1.13	1.09
C-1C	0.86	1.18	1.11	1.15	1.21	1.10
C -2A	0.95	1.09	1.05	1.08	1.14	1.06
C-2C	0.90	1.40	1.25	1.27	1.51	1.28
C-4	0.82	1.10	1.08	1.12	1.25	1.18
Retro-fitting	Steel, t	13.29	10.21	8.65	4.86	1.73
	Concrete, m^3	55.53	32.09	21.86	10.53	3.43
	Cost, Rs/m^2	29.47	18.93	14.39	7.25	2.57

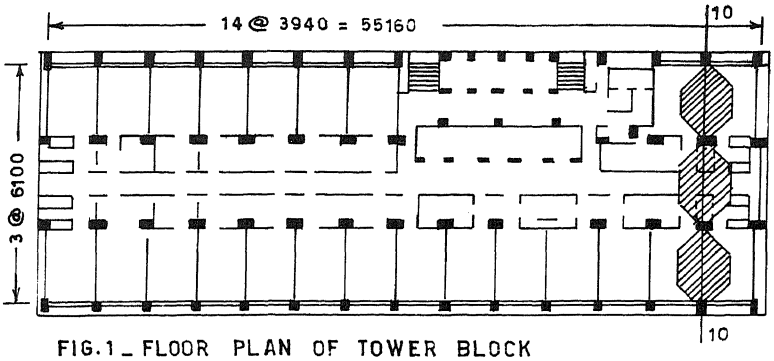

FIG.1 _ FLOOR PLAN OF TOWER BLOCK

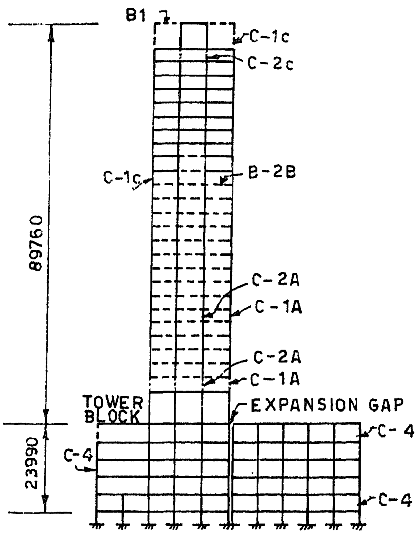

FIG. 2 _ STRUCTURALLY DEFICIENT MEMBERS IN DOTTED ALONG GRID 10

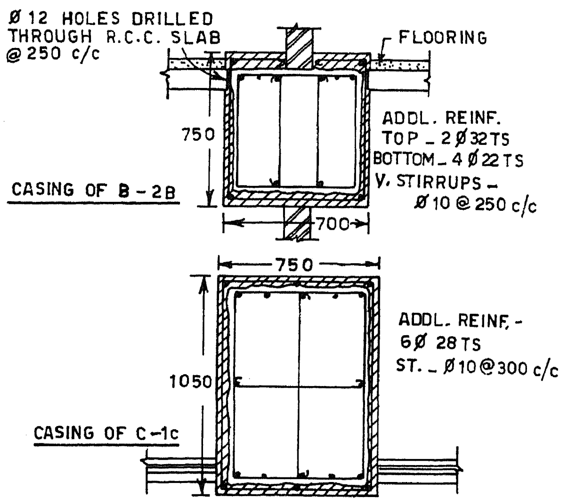

FIG. 3 _ CASING OF BEAM/COLUMN CASE I

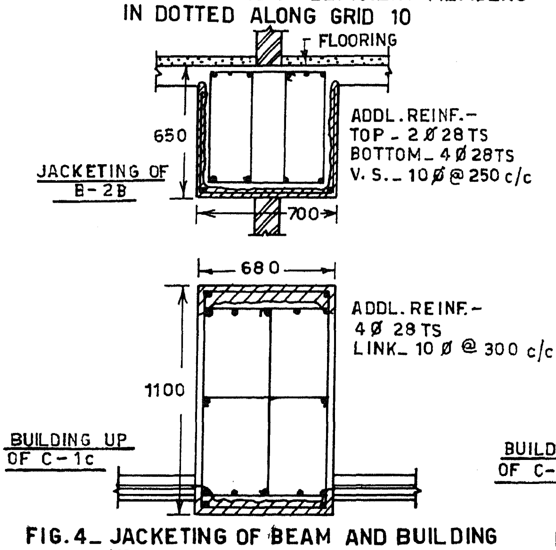

FIG. 4 _ JACKETING OF BEAM AND BUILDING UP OF COLUMN _ CASE II

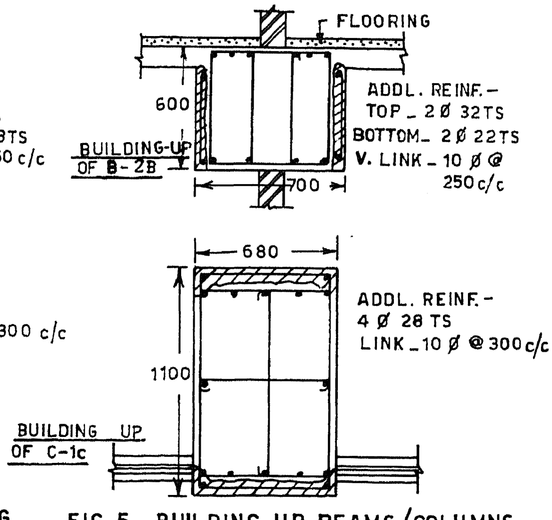

FIG. 5 _ BUILDING UP BEAMS/COLUMNS FROM TWO SIDES - CASE III

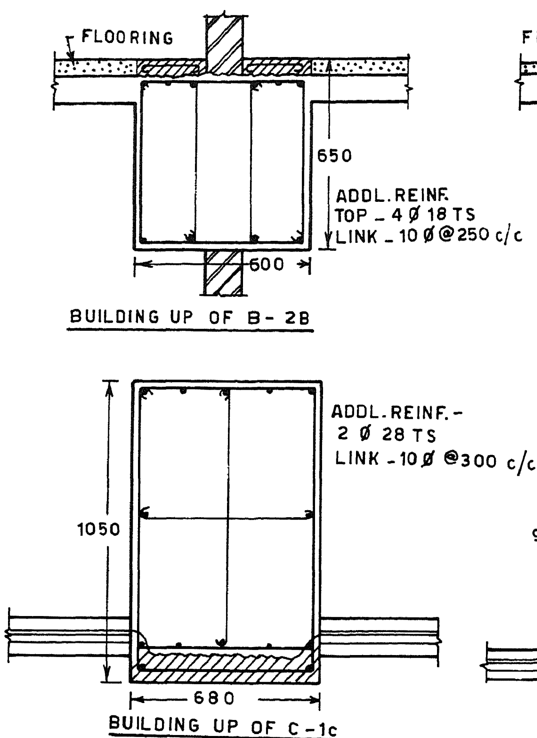

FIG.6 - BUILDING UP OF BEAM/COLUMN FROM ONE SIDE-CASE IV

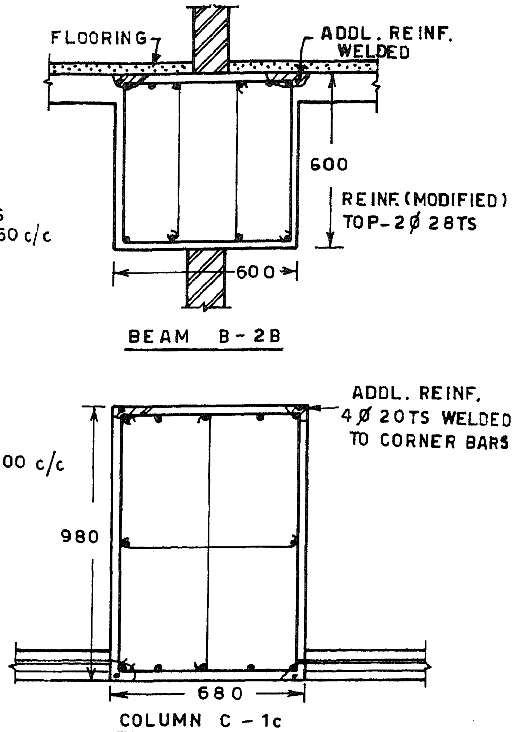

FIG. 7 - STRENGTHENING END PORTION OF BEAM/COLUMNS - CASE V

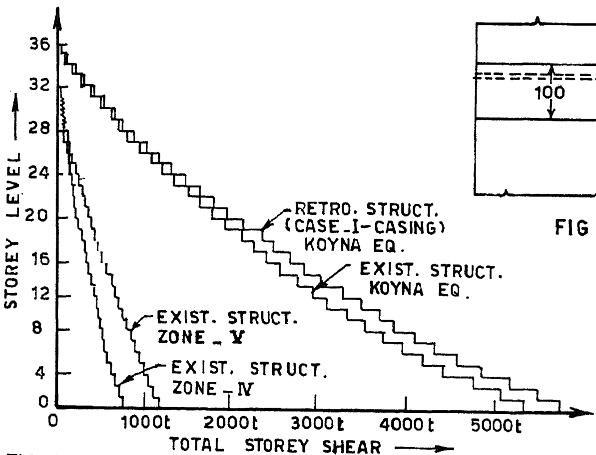

FIG. 8 - VARIATION OF TOTAL SHEAR ALONG HEIGHT

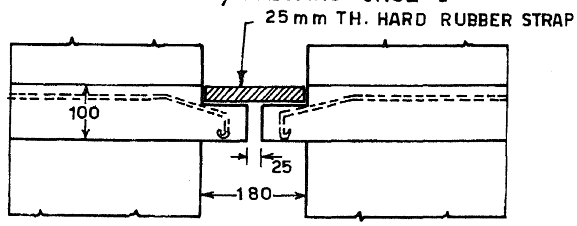

FIG 9 - EXISTING EXPANSION JOINT

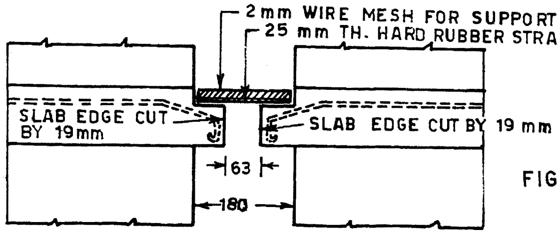

FIG. 10 - MODIFICATION OF EXPANSION JOINT