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Retrofitting of a Damaged School Building: A Case Study

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Abstract— A three story damaged school building which has developed multiple cracks in floor slabs is investigated and analyzed. The building vertical load paths are determined and failure patterns studied. The retrofitting (strengthening) measures are worked out. The building is provided with suitable strengthening features to limit the damage and prevent future damages.

Index Terms— Cracks, retrofit, strengthening, yield-line.

I. INTRODUCTION

The large numbers of school buildings particularly in India are constructed of brick masonry and unfortunately many of them are non-engineered structures and typical representative of traditional construction, as a result of which many of them are vulnerable to some serious kind of damage particularly in case of earthquakes. Keeping in view these facts, it was decided to evaluate and rectify a school building with structural deficiencies and fortunately we were able to locate one such school. The school building is located 7 km's from Srinagar city center. It is a three story load bearing masonry structure with an overall floor area of 131.6 m^2. It is 10 years old construction. The building is complex with RCC slabs at both levels with many overhanging projections. Though the school building looks safe from outside, but the cracks that were described by the owner and later on observed during the inspection compels for thorough evaluation and immediate retrofitting. Besides this, the building has many props that were installed after the construction. These props are mainly provided under the cantilever beams and overhang projections resulting in conversion of member from cantilever to simply supported, leading to reversal of stresses. The plan of the school building is also irregular. The school consists of large openings and during inspection many structural cracks were found at overhang projections that hint towards inadequate negative reinforcement at supports. Many other structural checks were performed that determined analysis and retrofitting of the building.

II. METHODOLOGY

The methodology of evaluating the un-reinforced masonry buildings is described by FEMA 307 [1].

1. *Inspection* is done by visual examination of the building, and the overall information about the structural system is obtained and possible errors regarding the structural layout construction and maintenance are identified. The condition of the structural and non-structural elements is verified and possible damage documented and categorized.

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2. *Monitoring* is done in case where the cause of damage, observed during visual inspection of the building are not evident, long term observations of the building's behavior are many times needed to know the actual reason, not all observed damage can be attributed to a single cause. For this purpose the structure is instrumented with displacement strain and vibration transducers and used to monitor the dynamic effects of structure. Settlement and tilting of the structure are measured with geodetic methods. The closings of the cracks are measured with deformeters; whereas velocity transducers are in most cases used for monitoring the dynamic effects.

3. *Analysis is done*- Evaluation and the analysis are started adopting the suitable methods. The various analytical methods available for evaluation of masonry structures are mainly governed by the masonry design codes IS: 1905 and SP: 20 the two BIS (Bureau of Indian standards). FEMA- 232 is a beautiful illustration of Homebuilders guide [2].

a. Vertical load on walls at various walls is calculated first. If load on the wall at level 1 is 'w_1' then pressure on solid masonry wall 'p_1' at various levels for a thickness of 't' is given by:

$$p_1 = {}^{w_1}/_{tx1} \tag{1}$$

Pressures at various levels are:

$$\sum p = {}^{w_1}/_{t\,x\,1} + {}^{w_2}/_{t\,x\,1} + \cdots \tag{2}$$

b. Horizontal load analysis is performed for earthquake load by equivalent static method adopted by IS-1893 [3]; whereby, base shear 'V_B' is

$$V_B = \frac{Z \times I \times S_a}{2 \times R \times g} \tag{3}$$

Z = Zone Factor, I = Importance Factor, S_a/g = Acceleration coefficient, R= Reduction Factor.

Lateral Load distribution 'Q_i' is given by:

$$Q_i = V_B \times \left[\frac{W_i {H_i}^2}{\sum W_i {H_i}^2}\right] \tag{4}$$

W_i = Seismic Weight of story 'i', H_i = Story 'i' Height.

c. Slab Analysis is performed by 'Yield line Analysis', which is based on the external energy expended is equal to internal energy dissipated. Ultimate moment along the yield line for slabs is 'm:

$$m = \frac{nL^2}{2\left(\sqrt{(1+i_1)} + \sqrt{(1+i_2)}\right)^2} \tag{5}$$

n = ultimate load on slab, L= span, i_1 and i_2 = ratios of supports to mid-span moments in two directions for one-way slab.

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