ICSF – 97
FIFTH INTERNATIONAL CONFERENCE ON STRUCTURAL FAILURE, DURABILITY AND RETROFITTING
Singapore 27 – 28 November 1997

REPAIR STRATEGIES OF A 10 STOREY OFFICE BUILDING

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SUMMARY

The present paper investigates the cracks that had developed in some of the floors and parapet walls soon after the construction of a 10-storied office building at Khulna in Bangladesh. The structural system of the building comprised of shear wall-frame interaction system. Two-way ribbed slabs were employed as roofs. The study attempts to identify the causes of the crack formation, the impacts of the cracks on the performance of the building and propose possible remedial measures. The slabs and the parapet walls had inadequate reinforcement. Ferrocement technology and other suitable methods were adopted for rectifying the design deficiencies.

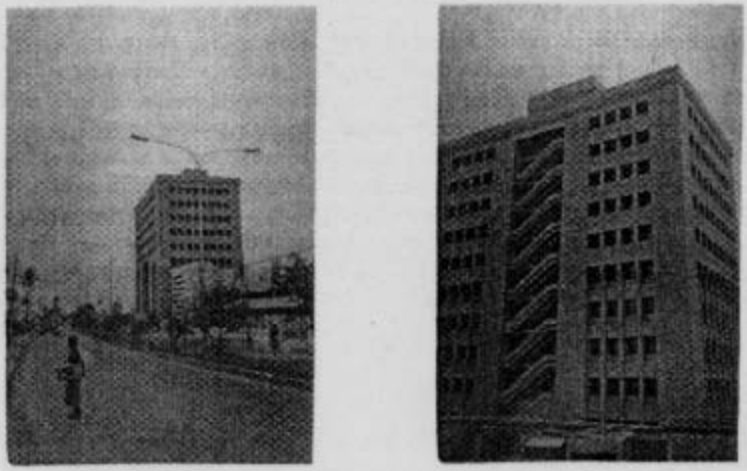
INTRODUCTION

The floors and parapet walls of a newly constructed 10-storied office building at Khulna in Bangladesh developed several cracks soon after the completion of the construction work and long before the whole building was subjected to office use. The paper attempts to identify the causes of the crack formation, the impacts of the cracks on the performance of the building and propose possible remedial measures. The paper is based upon a site visit and study of the reinforcement details of the cracked slabs and the parapet walls supplied by the owner of the building. The remedial measures recommended in the paper were subsequently adopted by the owner and were found to be very effective.

INSPECTION OF CRACKS

The authors visited the site of the 10-storied office building at Khulna in 1993. A preliminary study of the building was conducted initially. A more detailed investigation of the cracks was conducted later on. During the site visit, location and extent of the cracks were identified with the help of measuring tapes, fillet gauges and sophisticated optical devices. Photographs of typical cracks were also taken. While the front (west) and south side of the building under inspection is

shown in Fig. 1a, the back (east) and north side of the same building is given in Fig. 1b. At the time of site visit the structure was loaded upto level 4 (3rd floor) only.



(a) (b)

Fig. 1 (a) The front- (west) and south side and (b) the back- (east) and north side of the building

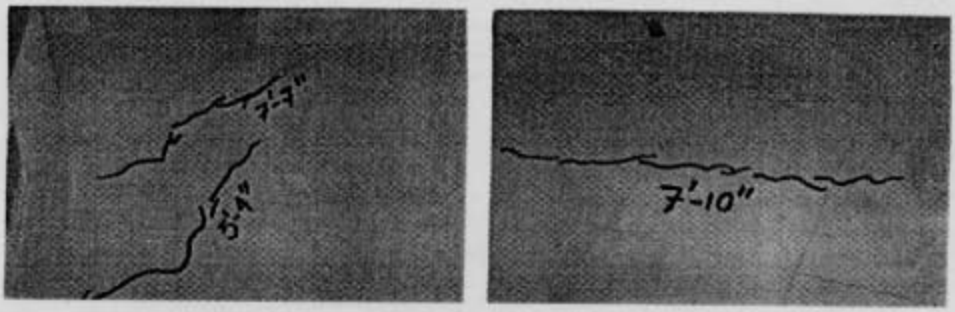
During the site visit it was observed that slabs of almost all the floors were cracked diagonally at most of the exterior corners. Horizontal cracks near the slab-wall interface were observed on the 4th and 6th floor. Figure 2a depicts typical diagonal cracks at the north-east corner of the slab of the 4th floor of the building. These 5'-4" (1625 mm) and 7'-7" (2311 mm) long cracks were about 0.15 mm wide. Similarly, Fig. 2b shows the typical horizontal crack at the North side of the slab of the 4th floor of the building. This crack in the figure is 7'-10" (2388 mm) long, about 0.12 mm wide and located at a distance of about 2'-5" (737 mm) from the wall. A detailed picture of the diagonal and horizontal cracks in the floor slabs can be obtained from Fig. 3, where crack positions in the 6th floor has been shown. Most of the cracks in the slabs had crack width ranging between 0.08 mm to 0.15 mm. Some of the diagonal cracks penetrated the whole depth of the top slab of the ribbed floors. Again, the parapet wall at the roof of the building contained major vertical cracks. These cracks extended from the bottom to the top of the wall. Figure 4 shows the approximate locations of such cracks with respect to the plan of the roof slab.

CAUSES OF CRACK FORMATION

The design details of the floor slabs, the slab ribs and the parapet wall of the newly constructed 10-storied building at Khulna was thoroughly checked and the crack patterns were examined in detail. Three distinct types of cracks originating from three different causes were identified. Detail observations with appropriate comments are summarised below:

i) The first type of cracks observed were typical diagonal cracks at almost all the exterior corners of the floor slabs. From the design details it has been understood that all the exterior corners were devoid of any corner reinforcement. It is worth mentioning that corner reinforcements are necessary to prevent corner uplifts of the exterior corners. Absence of

appropriate amount of corner reinforcement is believed to be the primary cause of these diagonal cracks at the exterior corners.



(a) (b)

Fig. 2 (a) Typical diagonal crack at the north-east corner and (b) typical horizontal crack at the north side of the slab in the fourth floor of the building

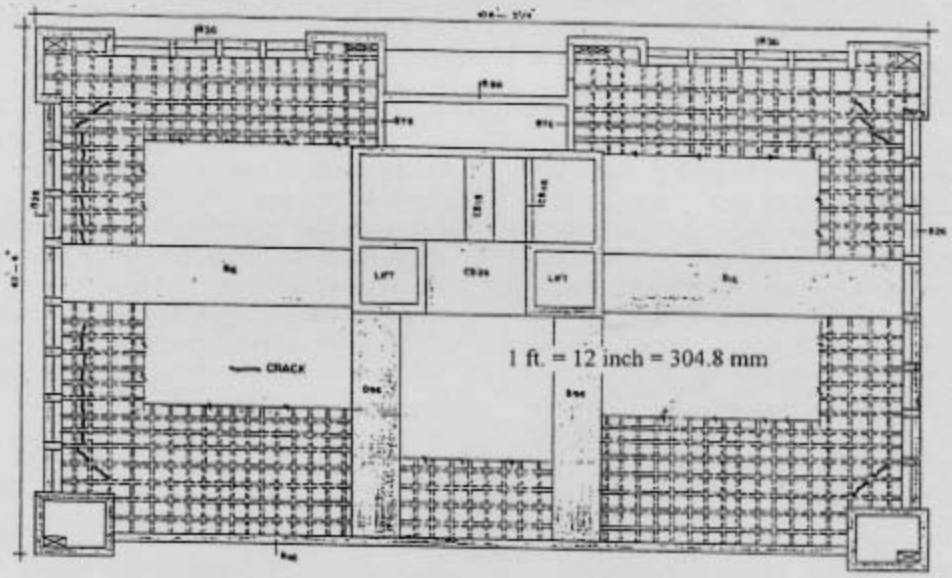


Fig. 3 Crack location in the 6th floor of the building

ii) The second type of cracks were observed on the 4th and 6th floor near the exterior wall and almost parallel to it. From the design details it was found that negative (top) reinforcement near the edge of the ribs supporting the slab was inadequate. Thus, the restraints near the edge supports of the ribs caused cracking parallel to the supports.

iii) The third type of cracks were the vertical cracks of the parapet wall at different locations. It has been observed that the longitudinal reinforcement provided in the parapet wall of the roof

was less than what has been prescribed as nominal temperature and shrinkage reinforcement in ACI Building Code 318-89 [1]. Considering the warm weather condition in Bangladesh and the fact that the parapet wall remains exposed to sunlight all day long, the amount of longitudinal reinforcement should have been even more than what has been prescribed in ACI Building Code.

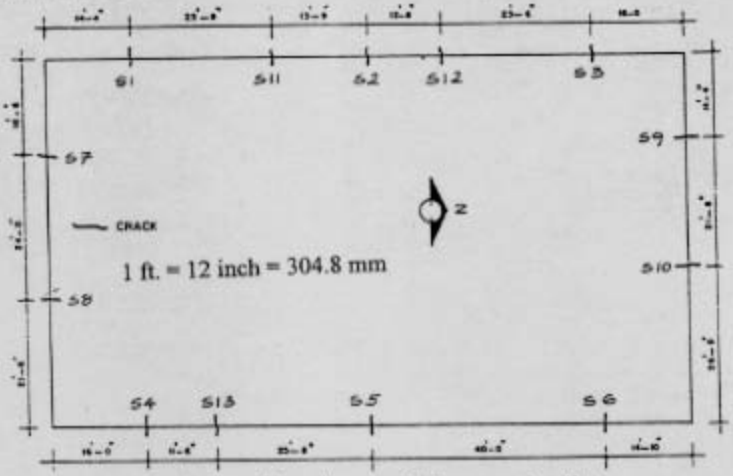


Fig. 4 Location of cracks in the parapet wall

INFLUENCE OF THE CRACKS ON THE PERFORMANCE OF THE BUILDING

The floor cracks, both diagonal cracks at the corners and cracks parallel to edges, were formed at a stage when the whole building was not fully loaded. The cracks, although have been found to be of very small width during the site visit, may widen in the future with subsequent loading. However, these cracks do not pose any serious structural problem. But as the cracks are expected to open up with the passage of time and given the highly humid weather condition of Khulna, it is envisaged that moisture may penetrate through the cracks and corrode the reinforcements in the floors. This may eventually cause spalling of concrete both at the top of the slabs (i.e. floors) and its underside (i.e. the ceiling). Some of the diagonal cracks have been observed to have already penetrated through the whole depth of the floor slab and were visible in the ceiling. In view of this, it was suggested that these cracks be repaired immediately and similar cracks, if formed in the future, be repaired soon after the formation of such cracks so that slab reinforcements may escape corrosion. As a guide-line, a time period of about six months, from the inception of cracking, may be considered as safe period within which repairing measures should be accomplished. The crack in the parapet walls has no significant influence on the overall performance of the building. However, rain water penetrating through the cracks may corrode the embedded steel and leave bad stains on the exposed surfaces. This would damage the aesthetic beauty of the building. So, it was deemed essential to repair these cracks on aesthetic reasons.

REPAIR METHODOLOGY

Both types of floor cracks were basically due to inadequate top reinforcements. So, cracked regions needed additional strengthening to prevent further cracking in future. Similarly,

inadequate temperature and shrinkage reinforcement triggered cracks in the parapet wall. Additional reinforcement along the length of the parapet wall and/or provision of expansion joints are deemed to be required. The remedial measures are described below under different heads referring to different types of cracks observed.

Repair of corners cracks

Calculate the number of cracked mosaic panels in each direction starting from the corner panel. Remove a square area of mosaic and mosaic bed (patent stone), each side of which will be equal to the length of the maximum number of cracked panels in either direction, plus the length of an extra panel and the distance between the wall edge and mosaic panels. Figure 5 shows the area of mosaic to be removed for repair of a typical diagonal crack at corner. Remove the mosaic bed carefully so that the structural slab beneath is completely exposed without much disturbance to it. The repair method is described below:

i) Scrub the exposed slab surface with steel brush; ii) Clean all dirt first by brushing with hand brush and then with a cloth duster; iii) Moisten the whole clean up area with potable water; iv) Place neat cement grout along the crack lines on the exposed slab. Grouting should not extend more than 75 mm on either side of cracks and should not be more than 2 mm thick; v) Ensure that the whole exposed area remains wet for about 12 hours after grouting; vi) About 12 hours after grouting, brush the exposed slab surface with neat cement slurry and quickly place 1 : 4 cement mortar mix over the exposed area trowelling it down to about 4 mm thickness; vii) Place 1.25 mm (20 Gauge) diameter galvanised wire mesh (12 mm x 12 mm size) covering the whole exposed surface. Place 8 mm diameter deformed bars (40 Grade) diagonally at a spacing of 100 mm centre to centre over the wire mesh laid diagonally as shown in Fig. 6; viii) Place micro-concrete mix (1 part cement : 2 part coarse sand (F. M. = 2.50-2.75) : 2 part small stone chips passing number 4 sieve) to cover the wire-mesh and diagonal rods placed earlier; ix) Place a second layer of wire mesh (having size and type same as given in step (vii) over the diagonal rods; x) Place 1 : 4 cement mortar over this wire mesh upto a thickness to bring up the existing mosaic bed level; xi) After 24 hours, lay the mosaic over this newly constructed reinforced bed.

Repair of floor cracks parallel to the exterior walls

i) Remove a rectangular area of mosaic and mosaic bed (patent stone) which will include area between the wall edge and the mosaic panels, all the cracked panels and an extra panel adjacent to every cracked panel. ii) All other steps are exactly the same as described for corner crack repair except that the 8 mm deformed bars at a spacing of 100 mm centre-to-centre between two layers of wire mesh are to be aligned perpendicular to wall face (see Fig. 7).

Repair of cracks in the ceiling (i.e. floor cracks visible from bottom)

Cracks visible in the ceiling may be repaired by first making a groove in the plaster along the crack line as shown in Fig. 8. Then, fill the groove with 1 : 6 cement mortar to which aluminium powder is added prior to mix preparation to make a non-shrink mortar. Amount of aluminium powder should be about one per cent by weight of cement or as found practicable from experience.

The repaired joint should then be white-washed/painted to match the colour of the ceiling surrounding the crack repair zone.

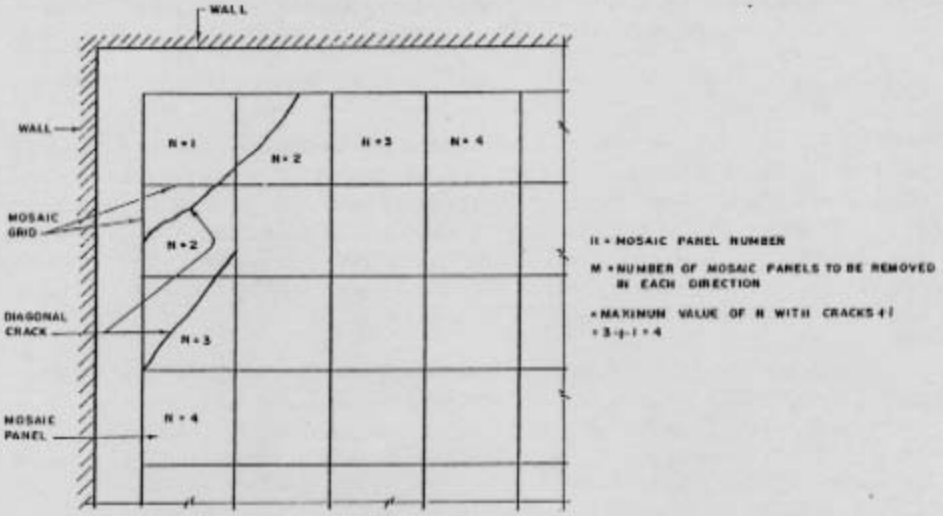


Fig. 5 Area of mosaic to be removed for repair of typical diagonal cracks at corner

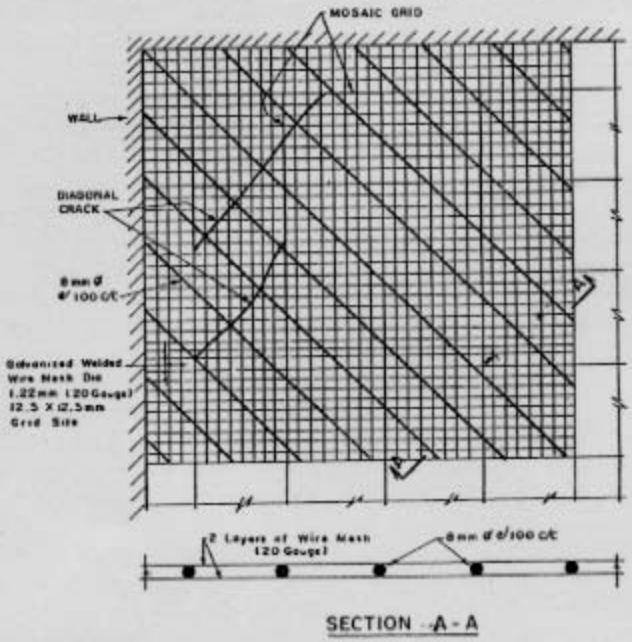


Fig. 6 Typical arrangement of reinforcement for diagonal crack repair

Repair of parapet wall

For repairing the cracks of parapet wall, two methods were suggested. Method I is extensive and aims at making up the deficiency of temperature and shrinkage steel of the existing wall. Method II is simple and aims at providing the heaving space.

Method I: Peel off about 20 mm plaster or concrete from all the exposed faces of the parapet including the top surface. Wrap up the parapet wall with two layers of 18 Gauge (1.4 mm diameter) 12 mm x 12 mm size wire mesh placed together (see Fig. 9). Fix up the mesh against the trimmed wall surface with suitably spaced steel pins. Then, cover these wire mesh with non-shrink micro-concrete (1 : 2 : 2) and restore the original dimensions of the wall. Provide 5 mm wide by 5 mm deep V-notch on the finished wall surface at about the same locations marked S1 through S10 in Fig. 4. Keep the chipped out surfaces moist for about 12 hours and apply a neat cement grout with hand brush just before applying the cement mortar/micro-concrete. Decorative wall finishing will follow the repair operation.

Method II: Provide expansion gaps at the parapet wall crack locations marked S1 through S10 in Fig. 4. This can be achieved by first chipping off the concrete from both sides of the crack, making an opening of about 50 to 60 mm. All the horizontal bars (binders) shall be saw cut from both ends and the pieces removed. Then carefully plaster the ends with 1 : 6 mortar mix to bring the final gap width down to about 20 mm. At the bottom of the opening, provide an inward slope so that rain water drains into the roof surface.

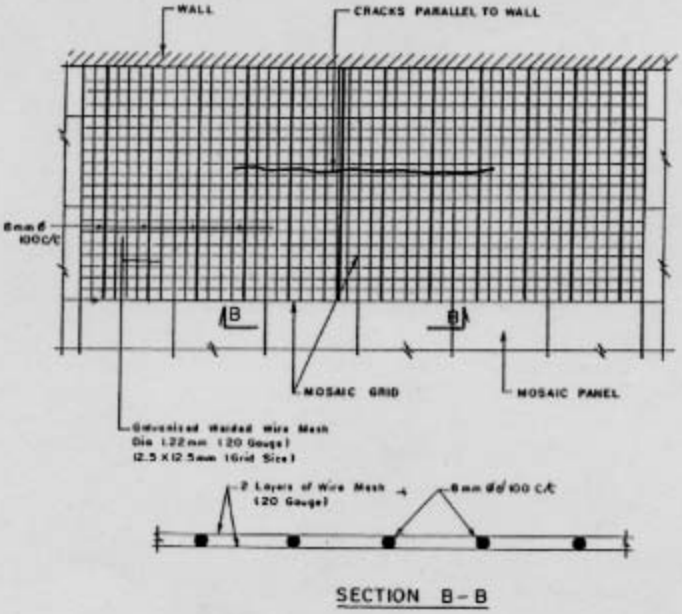


Fig. 7 Typical arrangement of reinforcement for horizontal crack repair

The cracks marked S11, S12 and S13 in Fig. 4 may be repaired by stripping 20 mm of plaster or concrete up to 300 mm on either side of the crack and then by wrapping this exposed surface of the wall with one layer of 18 gauge (1.4 mm diameter) 12 mm x 12 mm grid wire mesh. The mesh has to be covered with non-shrink micro-concrete (1 : 2 : 2) following the description given in Method I. Apply the decorative wall finishing to all the repaired areas in the parapet.

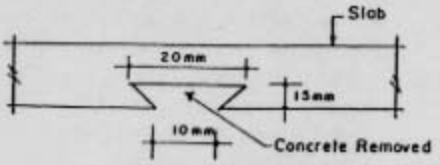


Fig. 8 Grove to be made for repair of cracks in ceiling

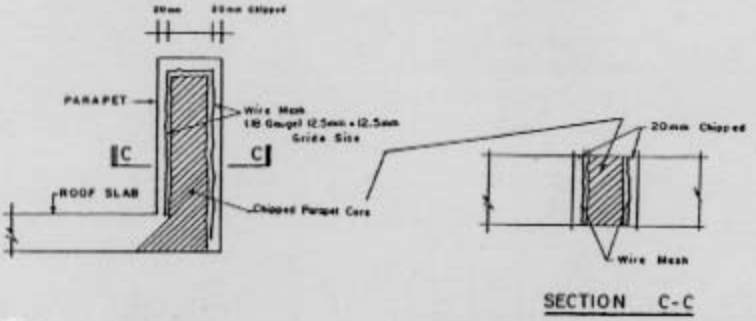


Fig. 9 Repair details of parapet wall

CONCLUSIONS

Detailed study of the existing design of a newly completed 10-storied office building at Khulna in Bangladesh has revealed inadequacy in the design/detailing of ribbed slab and parapet walls. Both types of floor cracks were formed basically due to inadequate top reinforcements. Thus, cracked regions needed additional strengthening to prevent further cracking in the future. Similarly, inadequate temperature and shrinkage reinforcement triggered cracks in the parapet wall. Additional reinforcement along the length of the parapet wall and/or provision of expansion joints were deemed to be required. The present study describes in detail the remedial measures that had been proposed and subsequently adopted successfully in an effort to rectify design lapses.

REFERENCE

1. ACI COMMITTEE 318, "Building Code Requirements for Reinforced Concrete (ACI 318-89)", American Concrete Institute, Detroit, 1989.