ASSESSMENT OF FLOOR SLABS IN THE BANDARANAIKE WING OF THE COLOMBO GENERAL HOSPITAL

by

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Abstract

Deterioration detected in the toilet floor slabs of the Bandaranaike Wing of the Colombo General Hospital led to an investigation to assess the current condition and future durability of the slabs and to ascertain the causes for deterioration. Although carbonation of slab soffits had taken place, there was sufficient cover to reinforcement for a period of around 20 years more. However, high chloride iron levels in the wet toilet floor slabs were identified as the probable cause of deterioration, and the demolition and reconstruction of these toilet slabs are recommended.

1.0 Background

The Bandaranaike wing of the Colombo General Hospital is a six storey block situated in Regent Street, Colombo 10. It was constructed by the year 1958, making it around 30 years old, when an investigation of the floor slabs was carried out in the latter part of 1988, on the request of the Project Implementation Unit of the General Hospital Rehabilitation Project.

A preliminary inspection of the structure indicated that toilet roofs on the 1st, 2nd and 3rd floors had deteriorated, with cracking and spalling of soffit plaster and concrete in the orientation of the reinforcement. The reinforcement was corroded and exposed in many places and the cover seemed to be very small. It should be noted that the above toilet roofs were those that had other toilets directly above them. Hence, it was considered likely that water from the toilets leaking through the concrete floor had accelerated the deterioration of those parts of the slab; such leaking was also evident.

The rest of the structure was reasonably free from visible signs of deterioration, except for the roof slab, which showed some signs of distress as described above. However, since the distress was not severe and since the concrete roof had already been covered by an additional roof,

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no investigations were carried out on the roof slab.

2.0 Objective & strategy

The objective of the investigation was to assess the current condition and future durability of the floor slabs. This involved testing of samples obtained from the badly affected toilet areas. However, samples were obtained for testing from corridor areas as well, not only for comparative purposes but also because visual evidence from the toilet areas suggested that the overall cover to reinforcement may be unacceptably small. The ward areas were not tested, so that minimum intrusion was caused on the functioning of the hospital.

The following tests were performed, in order to ascertain the condition and the causes for deterioration of the floor slabs:-

i) Depth of carbonation and cover, to check whether corrosion was due to the reduced pH value in concrete, caused by carbonation.

ii) Core testing, to check the adequacy of concrete strength.

iii) Chloride content in concrete, to check whether corrosion was due to high Chloride levels.

iv) Sulphate content in concrete, to check whether the concrete was affected by Sulphate attack.

v) Tensile strength of steel, to check the quality of the reinforcement.

Fourteen locations were selected to carry out tests (i) to (iv) and four locations selected to carry out test (v). These locations were confined to the three floors where distress was observed visually; they are indicated in figures 1 - 3, showing plan views of the above floors. The first digit in the code for location indicates floor level while the adjacent character, either T or C, specifies whether the sample was from a toilet or corridor area respectively; the next digit is merely a serial number. Of the fourteen locations, 8 were in toilet areas and 6 in corridor areas.

3.0 Procedure

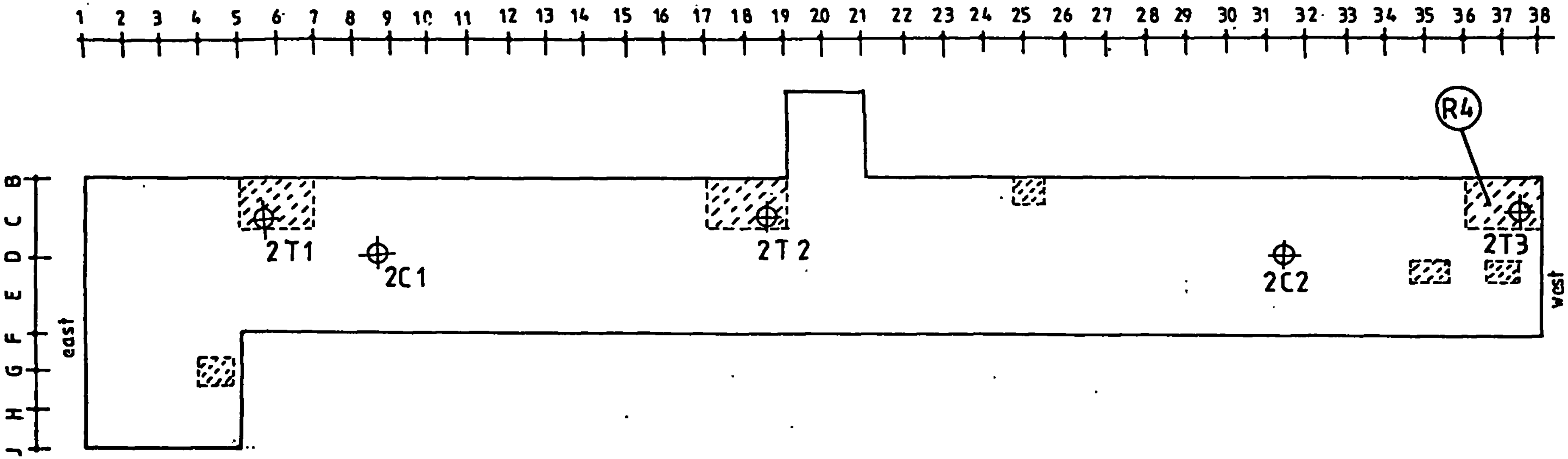
The floor rendering was removed and the top concrete surface exposed in the fourteen locations specified. Before a core was cut at a location, shavings from the uppermost surface of the concrete were obtained by using a masonry drill. These shavings were tested for Sulphate and Chloride content (and called series A), in order to verify whether these values varied through the depth of the slab.

Next, a core drilling machine was used to drill 55mm diameter cores vertically downwards. The machine was supported on the floor while an extendable arm which thrust against the roof ensured that the machine was held rigidly in place.

Immediately after the core was cut, phenolphthalein was sprayed onto the freshly cut cylindrical surface. The depth of carbonation was obtained by measuring the portions which remained colourless at the ends of the specimen.

The cores were removed to the laboratory and their ends cut and capped. In all cases but one the coring had cut through the reinforcement, which was closely spaced because it was of ¼ inch diameter mesh. Hence, the cover to reinforcement could be measured very accurately. Subsequently, a covermeter survey was also carried out to confirm the values for cover obtained in the above fashion.

The cores were crushed in a compression testing machine. Wherever possible, areas containing reinforcement were cut away from the two ends. Otherwise, an allowance for the presence of reinforcement was made, and the equivalent cube strength computed[1].

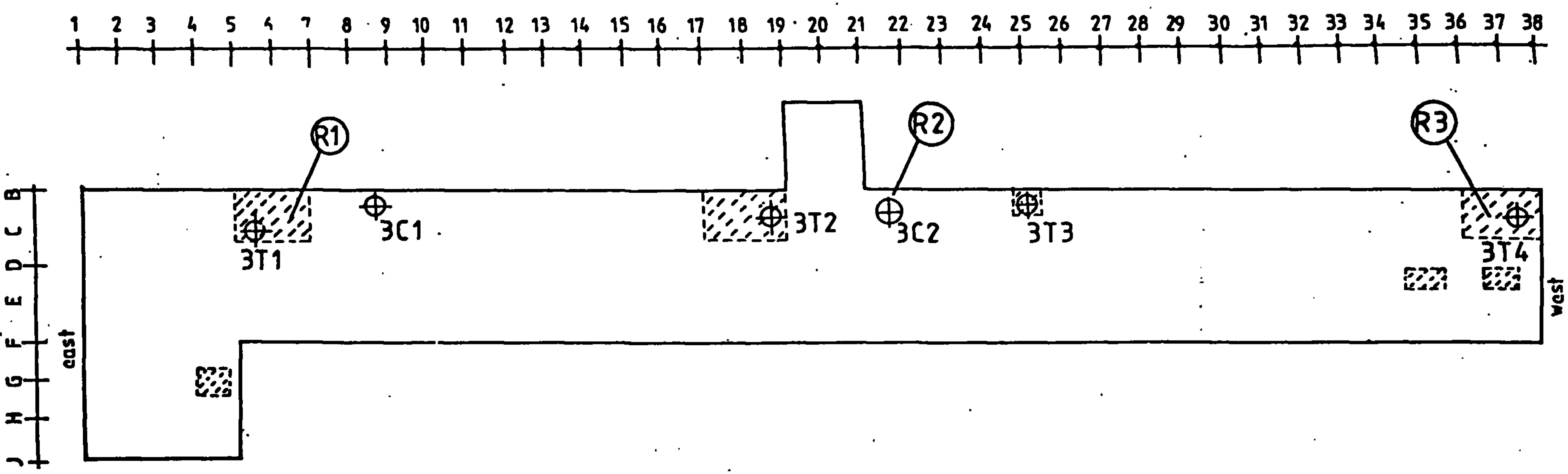


Grid lines = 3500mm = beam lines
Hatched areas indicate existing toilets / showers

Core

R 300mm sample of reinforcing bar
from soffit of slab

FIGURE 1 - COLOMBO GENERAL HOSPITAL
BANDARANAIKE WING, 2nd FLOOR SCALE
1:500



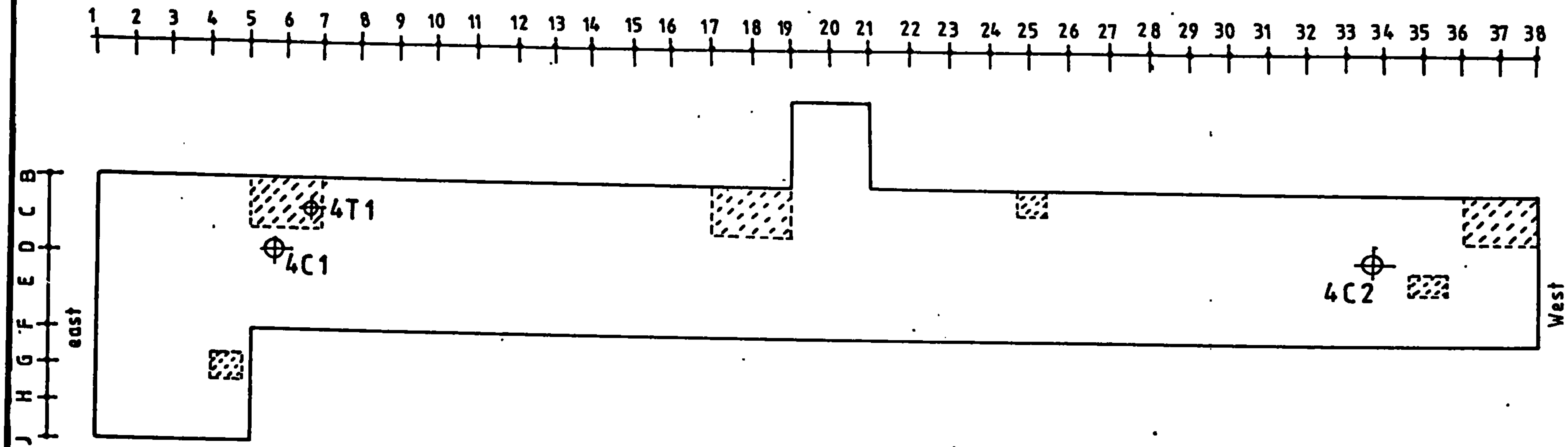
Grid lines = 3500 mm = beam lines

Hatched areas indicate existing toilets/showers

Core

R 300 mm sample of reinforcing bar from soffit of slab

FIGURE 2 - COLOMBO GENERAL HOSPITAL
BANDARANAIKE WING, 3rd FLOOR SCALE 1:500



Grid lines = 3500mm beam lines
Hatched areas indicate existing toilets . showers
Core

FIGURE 3 - COLOMBO GENERAL HOSPITAL
BANDARANAIKE WING , 4 th FLOOR SCALE 1:500

Portions from the centre of the crushed specimens (called series B) were tested for Chloride and Sulphate contents. The Chloride and Sulphate content tests were performed by the Ceylon Institute for Scientific and Industrial Research (CISIR).

The reinforcement for testing was removed from the four locations indicated in the figures. They were tested, in lengths of around 300mm, in a Universal Testing Machine, to determine their load carrying capacity. Subsequently, specimens were cut from unstressed areas and tested in a Hounsfield Tensometer in order to determine their actual tensile strength.

4.0 Results

4.1 General description

The results from the 14 concrete test locations are given in Table 1.

The following should be noted :-

i. The depth of carbonation and cover all correspond to the soffits of the slabs, which were protected by only a thin layer of whitewash. The tops of the slabs were protected by a cement-sand floor rendering around 20mm thick, and the depth of carbonation into the concrete below was zero in all cases. Hence, loss of durability due to carbonation was investigated only for the soffits of slabs.

ii. The covermeter survey confirmed that the values obtained for cover from these 14 locations were characteristic of the rest of the slab soffit areas.

iii. The high cube strength recorded for 2T2 was omitted from the summary statistics, as it was considered to be an outlier.

iv. The SO_3 and Cl^- contents are given as percentages by weight of concrete.

The results from the reinforcement tests are given in Table 2. The ultimate tensile load is a property of the actual bar, while the tensile strength is a property of the steel itself.

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4.2 Comparisons of means

One tailed t-tests at a 5% level of significance were used to compare the means corresponding to the corridor areas with those corresponding to the toilet areas. Paired t-tests at the same level of significance were used to make comparisons between the Series A and Series B results for SO_3 and Cl^- contents. The following are the results of these comparisons:-

i. No significant difference was found between corridor and toilet areas for depth of carbonation, cover, equivalent cube strength and SO_3 content. This implies that the overall means for these quantities can be taken as estimates of their absolute values.

ii. A significant difference was found between the Series A results (ie. concrete from the top surfaces) and Series B results (ie. concrete from the slab mid depths) for both SO_3 and Cl^- contents. This implies that there may be ingress of these chemicals from the tops of the slabs.

iii. A significant difference was found between corridor and toilet areas for Cl^- contents in both Series A and Series B. This implies that the ingress of chloride irons is much greater in the toilet areas than in the corridor areas.

TABLE 1 - Results of Concrete core testing

Location	Depth of Carbonation (mm)	Cover (mm)	Equivalent Cube Strength (N/mm²)	SO_3% Series A (top surface)	SO_3% Series B (mid depth)	Cl^-% Series A (top surface)	Cl^-% Series B (mid depth)
2C1	28	30	15.72	0.62	0.23	0.07	0.05
2C2	10	10	11.97	0.65	0.14	0.08	0.07
3C1	20	13	12.81	0.39	0.20	0.08	0.05
3C2	30	---	15.26	0.63	0.17	0.13	0.10
4C1	29	17	17.95	0.44	0.24	0.09	0.06
4C2	10	12	15.38	0.44	0.22	0.12	0.06
Mean	21.17	16.4	14.85	0.53	0.2	0.095	0.065
S.D	9.35	8.02	2.16	0.12	0.038	0.024	0.019
2T1	23	25	17.14	0.54	0.21	0.14	0.06
2T2	0	30	43.50*	0.33	0.13	0.13	0.15
2T3	0	30	18.72	0.77	0.11	0.23	0.12
3T1	0	8	12.56	0.25	0.14	0.15	0.08
3T2	15	30	11.79	0.33	0.22	0.28	0.09
3T3	6	19	26.73	0.20	0.26	0.19	0.34
3T4	38	18	12.48	0.13	0.15	0.58	0.05
4T1	0	7	20.17	0.43	0.23	0.24	0.10
Mean	10.25	20.88	17.08	0.37	0.18	0.243	0.124
S.D	14.11	9.54	5.40	0.205	0.055	0.146	0.093
Mean	14.93	19.15	16.05	0.44	0.19	0.179	0.099
S.D	13.12	8.92	4.32	0.186	0.048	0.133	0.076

* eliminated from summary statistics, as an outlier.

5.0 Interpretation of results

5.1 Equivalent cube strength

The minimum acceptable equivalent cube strength within a structure made of grade 20 concrete (ie. the lowest grade permissible for structural concrete), can be considered to be 20/1.5 = 13.33 N/mm²[1], if it is being checked against the requirements of CP 110. Table 1 indicate that the lowest result is 11.79 N/mm², which is just 1.54 N/mm² lower than the requirement. Hence, the concrete strength in the structure could be considered as being a little unsatisfactory.

The target mean strength in the structure can be taken as (20+1.64x 4.32)/1.5 = 18.06 Nmm². Here again, the overall mean for the equivalent cube strengths, which is 16.05 N/mm² could be considered as being a little unsatisfactory.

It should be noted that this slightly unsatisfactory situation is accepted in the context on most of the cores being taken from the worst affected areas in the slabs.

5.2 Depth of carbonation and cover

The overall means for depth of carbonation and cover on the soffits of slabs are 14.93mm and 19.15mm respectively. Assuming that the depth of carbonation is proportional to the square root of time[3], the variation in depth of carbonation with time is given in Table 3.

This table indicates that if the life span of the building is expected to be more than 50 years (ie. more than 20 years from the time this investigation was carried out), some protective barrier[4] has to be provided to retard carbonation; otherwise, carbonation may lead to the corrosion of reinforcement, in 20 years' time.

Tables 1 and 3 also suggest that carbonation is not the main reason for the reinforcement in the toilet areas being badly corroded, since depths of carbonation at the time of investigation are, in general, less than the concrete cover. A notable exception to this is location 3T4, where the depth of carbonation is very high compared to the concrete cover. It should be noted that a sample of reinforcement taken from this area was very badly corroded, giving very low load carrying capacity (ie. sample R3 in Table 2).

5.3 Sulphate content

The overall means for Sulphate content as a percentage by weight of concrete are 0.44% and 0.19% for Series A and Series B respectively. If a cement:concrete ratio of 1:7 is assumed, the greater percentage of SO_3 by weight of cement is 0.44x7 = 3.08%, which is less than the 4% allowed in BS 8110[2]. Hence it may be concluded that sulphate attack was not the cause of concrete degradation; neither is it likely to pose a major threat in the future.

5.4 Chloride iron content

A summary of the means of the chloride iron content as a percentage by weight of concrete is given in Table 4. According to reference (3), a percentage of upto 0.05% is considered to be a low risk situation while one greater than 0.15%, a high risk situation; percentages between 0.05% and 0.15% are considered medium risk situations. If the source of chloride iron is external, the above limits should be lowered.

By the above criteria, the toilet areas are in the high risk (Series A) and the upper end of medium risk (Series B) categories. Furthermore, since there is probably ingress of Cl^- from the top of the slab and since the slab is wet, there is a very high risk of reinforcement corrosion taking place. The main cause of reinforcement corrosion

TABLE 2 - Results of reinforcement testing

Specimen No.	Location	Ultimate tensile load (kN)	Tensile strength(N/mm^2)
R_1	Toilet	20.04	678.50
R_2	Corridor	21.16	660.00
R_3	Toilet	3.53	629.15
R_4	Toilet	23.38	678.50

TABLE 3 - Depth of Carbonation and Cover

Time,T(years)	Depth of Carbonation,d (mm)	Cover (mm)	Remarks
30	14.93	19.15	Cover is OK
50	19.27*	19.15	Cover is OK
80	24.38*	19.15	Cover is not enough

* Estimated on the basis of $d \propto T^{\frac{1}{2}}$

TABLE 4 - Chloride ion percentage by weight of concrete

	Top Surface(Series A)	Mid Depth(Series B)	Condition
Corridor Areas	0.095	0.065	Dry
Toilet Areas	0.243	0.124	Wet

at the time of investigation was also probably these high chloride levels in the wet slabs. The only solutions for a reinforced concrete slab in this condition are cathodic protection[5] or demolition and reconstruction.

The corridor areas, on the other hand, are in the lower end of medium risk category (both Series A and B). Furthermore, since the slabs are dry, the risk of corrosion is much less than in the toilet areas.

The generally high Cl^- levels may also indicate that sea sand was used in the original construction work.

5.5 Reinforcement testing

The Hounsfield Tensometer results show that the actual tensile strength of the steel is well above required values (Table 2). The ultimate tensile load carried by the bars themselves are satisfactory for a ¼ inch mild steel bar where R_1, R_2 and R_4 are concerned - ie. the load carrying capacities of these bars have not been significantly affected by corrosion.

However, where R^3 is concerned, its load carrying capacity has been severely reduced due to corrosion. It should be noted that the sample R_3 was taken from a toilet area adjacent to the concrete core location 3T4, where the depth of carbonation was found to be much greater than the concrete cover.

6.0 Main conclusions & recommendations

1. The reinforcement corrosion which led to the deterioration of the floor slabs in the toilet areas is very likely to have been caused by high chloride iron levels in wet concrete.

2. The floor slabs in the toilet areas should be demolished and reconstructed (if a cathodic protection scheme cannot be provided), because the above high chloride iron levels in wet concrete constitute a continuing risk of reinforcement corrosion. Care should be taken to provide proper water proofing of the slab during the reconstruction.

3. Where deterioration as a result of carbonation is concerned, the floor slabs are safe for around 20 years from the time of investigation, without any treatment. If their life is to be extended beyond this, they will need a protective barrier to be applied immediately.

7.0 Acknowledgement

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8.0 References

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