Damage assessment and rehabilitation of concrete structures: Three case studies

I refer refer to the article "Damage assessment and rehabilitation of concrete structures: Three case studies" by Mr B Sivagnanam - published in *The Indian Concrete Journal*, December 2002, vol. 76, No. 12, pp 764 - 770.

My congratulations to the author for his interesting approach to deal with problematic case studies for distress resolution. It offers relief to the structures through repairs and restoration. I am familiar with these types of problems. Hence my comments to initiate interest and dialogue amongst the fraternity. At times there is a tendency to overdo the applications of one of the techniques. At the same time, one may be biased and then try to find out the causes in relation and correlate it accordingly. It all depends on exposure, awareness and extent of experience dealing with the problem. My short observation for these case studies are given below.

Case studies 1: Damage due to lack of maintenance

Preliminary investigation by USPV and grouting could be superfluous. Grouting consumption is not stated. It may be hardly anything and may not be worthwhile. Large cross sections of columns of turbo generators are generally well concreted with compact and dense concrete. Local honey combing would not effect vibrationary tendency and need not be a cause of concern. Locations of vibrations if monitored would point out that vibrations are from top downwards, that is, the source and cause of initiation.

The author has correctly identified eccentric rotational torque due to improper assembly. These are the areas of mechanical maintenance department who have general superiority over civil engineering departments. It is a general practice that the buck is passed on to the civil engineering aspects, that is, design, construction etc. Hence we should be alert and aware about various modes and pattern of the structural performance.

Case study 2: Damage due to fire

It is quite interesting that the author has taken systematic and bold analytical approach for decision making. For investigations, impact hammer and USPV tests were relied upon. He has not gone in for other detailed investigations such as DGA and DTA. He has also not dealt with the data, information and observations dealing with fire travel path and co-relation of localised damage with reference to damage in the vicinity. It is generally experienced that fire damage, at many time are localised only, that is, part of the element is damaged while keeping the structural joint intact.

The extent, severity and variation of colour of the fire damaged concrete is also a good indication about probable temperature range and its penetration from cover within. Available protections, if any, such as cover, plaster, paint, stone façade etc. offer lot of relief of fire penetration. Duration of fire with distress mapping of the entire structure, study of fire damaged debris would collectively permit to assess a more realistic "feel " about what was the level of damage and the "margin" between repairs and acceptance. However, approach of the author was judicious as he opted for a method of restoration in view of limitations of production working areas and their availability.

Case study 3: Damages due to unexpected operational problems

Such problems are localised and sporadic. They need to be recorded as a compendium and widely circulated to enable maintenance engineers, to find out what could be the problem, cause of damage and how to set it right. The author has done intelligent guess work in identifying the cause and source of damage. However, his "detailed investigations" and strong logistical experience behind it need to be elaborated. The repairs are over six years old now. Would there be any repeat damage at the same place or else where since these locations are prone to unidentified and damage within, if and when the structure undergoes some unexpected working environment?

My heartiest congratulation to Mr B. Sivagnanam for his consistency in maintaining records and then documenting it for the benefit of the engineering fraternity.

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This letter is a sequel to the article "Damage assessment and rehabilitation of the concrete structures: Three case studies" by

Mr B. Sivagnanam that appeared on pp. 764-770 of *The Indian Concrete Journal*, Vol. 76 No 12, December 2002 issue. It is heartening to know that practising civil engineers do now and then come forward to write papers on their works.

Fig 4 depicting a view of the fire affected beam of the turbine hall is quite revealing and urges one to respond. The process steam plant structures, was constructed in the early 60s, that is, 40 years ago. The structures performed their duties in the fertiliser factory producing urea and were exposed to a high concentration of urea fumes in the atmosphere as the prilling tower is an adjacent structure. Inspite of the extreme exposure conditions, all the reinforcement bars are intact as revealed from the photo. The reinforcement bars have not been subjected to corrosion in the last four decades of its life. It clearly reveals that the corrosion problems of RC structures now faced by developed as well as the developing world is entirely due to quality of steel presently available in the market. With the advent of high strength deformed bars in various nomenclatures, we have faced problems in concrete structure wherein durability is a highly debatable topic. A new terminology 'high performance concrete' has entered in the glossary of concrete technology, whereas the real culprit is steel.

Will the present day steel ensure durable concrete structures?

The much awaited revision of IS 456 at last materialised in July 2000. The revision incorporates a number of important changes. For example, it states:

"In recent years, the durability of concrete structures have become the cause of concern to all concrete technologists. This has led to the need to modify the durability requirements world over. In this revision, the earlier clause on durability has been elaborated and a detailed clause covering different aspects of design of durability structures has been incorporated".

The new codal provision are intended to enhance the durability of concrete structures. We are taking steps to improve the quality of concrete, its impermeability, its resistance to several environmental exposures etc. What about the steel? Is the fact that steel is produced in factory adequate to assure the quality of steel?

In this connection the writer would like to narrate an experience. During the construction of Panban Bridge, large quantities of structural steel especially rolled steel joists for various temporary and enabling works had to be used. The department supplied from its stock old joist manufactures in 1914, just before the First World War. The new joists were supplied from the public and private sectors steel companies. The new steel joists procured from these sources showed red spots all over the very next day of arrival at site. Immediately thereafter primary coat was applied, followed by two coats of painting. As Mandapam is a corrosion prone area the speed with which it corroded was thought justifiable.

However the steel joist manufactured in 1914 and supplied by the department from the old stock remained unaffected in the very same location for months. It clearly demonstrates that there is a deterioration in the quality or the metallurgy of the steel presently produced.

Unfortunately civil engineers do not raise this issue in any forum. There is so much of discussion on durability of concrete structures. The metallurgy of steel also plays an important role in the durability of reinforced or prestressed concrete structures. It is high time this aspect is brought to focus. Research institutions should study the early corrosion of the present day steel and of the yester years steel and analyse the cause for early corrosion of the present day steel.

Hence, the writer would appeal to the researches to study the quality of steel with special reference to corrosion. With these findings the steel industry could be impressed upon to improve on the quality of steel with special reference to corrosion resistance.

(While we respect the observations made by Mr Srinivasan, as also his views on the subject, we would like to draw the readers attention to the views expressed by Dr C.S. Viswanatha on the same subject on page 862 — *Editor*).

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The author's reply

I am happy to reply to the queries/remarks made by Mr R.N. Raikar and Mr D. Srinivasan on my article and at the same time I am also delighted that my article has created interest amongst the engineering community.

All the three works indicated were done by me during the year 1996 -1997. The article published in the Journal is only an abridged and shortened version, and due to the space constraints all the details could not be given.

Hope the following answers will clarify Mr Raikar's queries.

Case I: Damage due to lack of maintenance

Of course, large cross section of columns of turbo generators (TG) are generally well concreted but the vibration data collected on the columns of TG foundations revealed that columns C4 (South) and C5 (North) experienced relatively high vibrations and gave room for suspicion of likely presence of voids in the region of 0 to 2 m and 6 to 7 m from the base of the columns. Ultrasonic pulse velocity data showed that concrete in the columns namely, C1 (North), C4 (South) C5 (North) and C6 (South) are below satisfactory indicating the presence of voids and loss of integrity. In addition C1 (South) was also identified to possess a few isolated locations of unsatisfactory concrete.

It was also reported that the machine vibration had occurred due to dislocation of wedges in the generator rotor. Therefore, it may not be possible to exactly confirm whether the vibration is due to mechanical problem or loss of integrity of concrete.

The identified weak zones in the columns were subsequently improved by grouting with non-shrink cement/epoxy. The repaired zones were subsequently scanned by UPV test to confirm the order of improvement realised in pulse velocity after the repair was carried out. Using the new values of pulse velocity so obtained after the repairs, the dynamic modulii of in-situ concrete in different regions of the repaired column were again taken and these values indicate that there was improvement in the vibratory performance of the columns. (As there were still some high vibratory amplitudes in the generator and bearing area, the rotor was changed). Thereafter, the vibratory performance of the TG was found satisfactory and was put to use. Till date, the structure is functioning without any problem. Regarding grouting consumption for the columns, around 4750 kg of cement, 442 kg of high-molecular weight thermoset polymer and 255 kg of epoxy was used.

Case 2: Damage due to fire accident

The fire affected structure and the status of some of the components of the structures such as aluminium, glass panes; reinforcements were visually inspected. There was no appreciable deformation in the concrete members.

During inspection aluminum articles were found to have melted indicating the fire temperature to be of the order of 800°C.

The colour of concrete in the fire affected area was found to range between greenish grey to pink indicating the fire temperature to be of the range of 300°C to 600°C. The DTA/TGA tests could not be conducted to assess the temperature during fire.

Since the concrete structural members exhibited substantial cracking, spalling and debonding of concrete from reinforcement, it was decided to do non-destructive testing to find residual strength of concrete, *Table* 1.

Core sampling and testing were carried out at select locations using portable core cutting machine. The test results indicated fire temperature to be in the order of 400-600°C.

The reinforcement in several locations was found to be exposed, particularly at the top portions of some of the columns. The visual examination indicated that the reinforcements were subjected to a substantial temperature rise. In order to assess the residual properties of the reinforcement, samples from different locations were collected and tested mainly for yield and ultimate strength, percentage elongation and modulus of elasticity. The test result showed that the fire temperature was of the order of 400°C and that the rebars were not affected.

Table 1: Core sample results for case 2

Sample mark and location	*Estimated cube compressive strength, N/mm^2 (as per BIS)*
1AB	23.44
1A(AB)	21.56
2BC	14.33
3DE	30.16
4EF	23.53
5FG	23.5
6BC	8.42
7CD	16.26
8DE	18.26
9EF	16.15
10FG	21.91
11DE	18
13CD	14.56

As already mentioned, field testing and repairing the fire-affected members were simultaneously executed. This gave a chance to conduct UPV test, as a sample, on one of the members, after repair. The member was tested in the deaeration/control room portion. Testing was done after 3 days of repairs. From the UPV values for this beam, considerable improvement was noticed in the integrity of concrete. The actual value was 2.86 km/s. Although this value does not qualify the condition of concrete as good to very good, this can be considered as satisfactory considering the fact that the age of repaired beam was only 3 days at time of testing.

Case 3: Damage due to unexpected operational problems

As Mr R.N. Raikar pointed out, this problem is unique in nature. Since the RC pressure tunnel takes a 90° turn, located opposite to CW pump house, this curved portion had been subjected to enormous pressure. This pressure had caused the distress and could be attributed to the following reasons.

During the sudden stoppage of the pumps, the pressure due to surge/water hammer is likely to be ten times or more than the operating pressure of 1.75 kg/cm^2. In case of malfunctioning of the valves provided in the CW pump house, the pressure rise would be of the order of 4 to 5 times the normal condition.

Since its inception, CW pumps had tripped suddenly 24 times and at the 24th time the RC portion in the bend was damaged. The sudden tripping and the automatic closure of the valve caused a cavity in the tunnel, which is at high vacuum, causing the water to flow opposite to the direction of flow and with enormous weight of water coupled with suction attacks the 90° bend, which offers resistance to flow against a force of 20 Ksc. This force takes longer time to die down and repeatedly attacks the bend causing damage progressively, ultimately at the 24th instant the tunnel had broken down.

Non-provision of automatic pressure release valve is considered to be the cause for the deterioration of the tunnel.

Rebar corrosion

As Mr D. Srinivasan has stated, it is true that the process steam plant building was constructed 40 years back and it is located inside a fertiliser factory producing urea. The whole surroundings are exposed to high concentration of urea fumes. Inspite of the extreme exposure conditions all the reinforcement bars were intact and the reinforcement bars have not been subjected to corrosion.

Moreover the rebars in the circulating water tunnel were also intact in Case 3. The RC pressure tunnel which takes a 90° turn located opposite to circulating water pump house in our second thermal power plant were subjected to enormous thrust by the water mass due to surge/water hammer effect and delaminations have occurred in many locations at the 90° bend. While the affected concrete was removed, the exposed reinforcements were afresh and as good as new ones. This was quite encouraging to us in undertaking rehabilitation works. It may not be out of place to mention that 1 ppm of chlorine was administered in CW pump house to avoid algae growth and the same water travels through the tunnel.

At present, after seven years no abnormality was noticed. In fact, during long shutdown period the whole tunnel was dewatered and inspection was carried out, not even wet patch dampness was noticed in the affected area.

Under these circumstances, I fully agree with the views of Mr D. Srinivasan that the corrosion problems of RC structures now faced by the developed as well as the developing world is essentially due to the quality of steel presently available in the market.

As Mr Srinivasan feels, the metallurgy of the present day steel plays an important role in the durability of reinforced or prestressed concrete structures. R&D institutions should analyse the difference between present-day steel and the yester years steel and firm up the cause for early corrosion of the present day steel.

All these would lead to improvements of the quality of steel with respect to corrosion resistance.

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