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Strengthening of a Prestressed Concrete Shell Structure

Renforcement d'une coque en béton précontraint

Verstärkung eines Spannbeton-Schalentragwerkes

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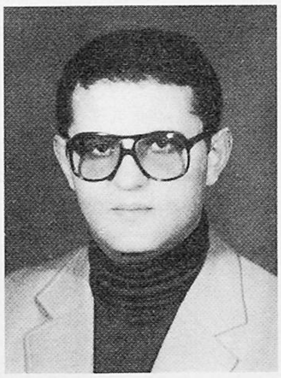

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SUMMARY

In this paper, strengthening of a prestressed concrete shell in a chemical factory, in Cairo, is presented. The valley beams were strengthened by external prestressing cables anchored outside the building in precast end blocks. The shells were strengthened by casting 4 cm thick resin concrete on top of the existing shell.

RESUME

L'article présente le renforcement d'une coque en béton précontraint pour une usine de produits chimiques au Caire. Les poutres des extrémités ont été renforcés par das câbles extérieurs en précontrainte. Ces câbles ont été fixés par des blocs aux extrémités. Les coques on été renforcées par coulage de 4 cm de béton de résine sur la surface des coques existantes.

ZUSAMMENFASSUNG

Der Bericht behandelt die Verstärkung einer vorgespannten Schalenkonstruktion in einer chemischen Fabrik in Kairo. Die Schalenrandbalken wurden durch äussere Vorspannglieder verstärkt, die ausserhalb der alten Konstruktion in vorgefertigten Stahlbetonblöcken verankert wurden. Die Schalenhaut selbst wurde durch das Aufbringen einer 4 cm dicken Harz-Betonschicht verstärkt.

1. INTRODUCTION

In this paper strengthening and repair of a prestressed concrete shell is discribed. The building under consideration, which was constructed in the late forties, is an industrial building in a chemical factory in the area of greater cairo, Egypt.

The building is devided in to four identical parts separated by three expansion joints as shown in fig.1. Each part is composed of three cylindrical reinforced concrete shells with prestressed edge beams. Each shell is 10ms wide, 16ms long and 6cm thick. The intermediate edge, valley, beams were prestressed with three FREYSSINET cables 12 o 5 mm while the exterior beams were prestressed with only two cables of the same type.

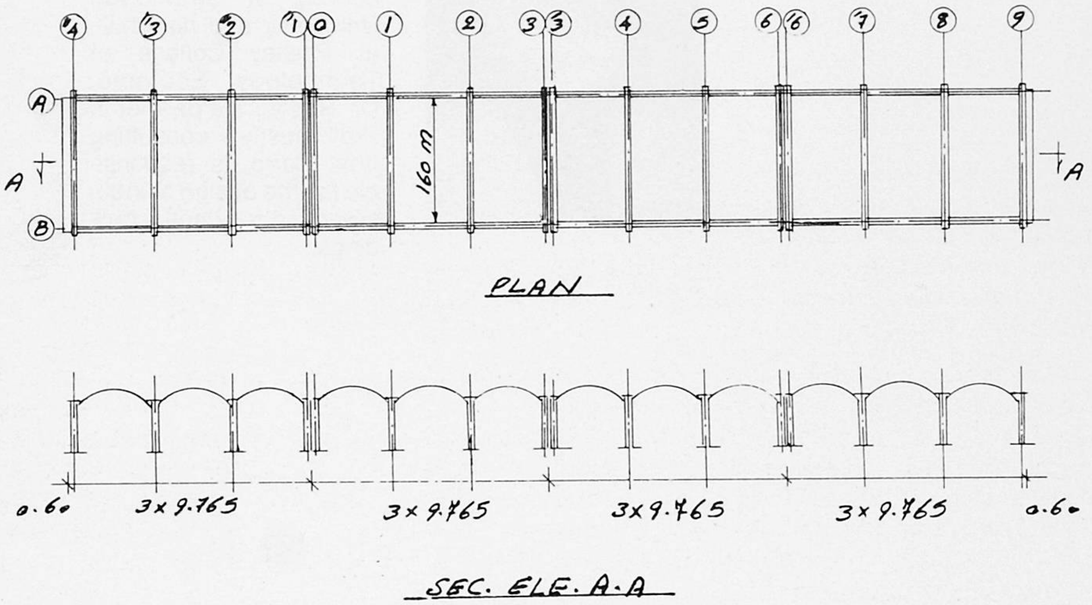


Fig. 1 General Layout

2. DAMAGES OBSERVED

2.1 Discription Of The Damage

In 1978 i.e. thirty years after construction, sudden collapse of the first part took place.

The factory manager requested a thorough investigation to the rest of the building in order to ensure the adequate safety. The following damages were recorded in the remaining three parts:
- In the webs of the prestressed beams - especially for those of the intermediate beams- several cracks spaced about 50cm between each other were noticed at mid-span. These cracks were extending vertically about 60cm from the bottom surface of the beams with crack widths varying from 0.5 to 3mm on both sides and on the bottom surface of the beams as shown in fig.2.
- In some localized areas of the shells, longitudinal and transversal cracks on the inside face and sometimes on the outside face were noticed. In these areas one can assume that the concrete is linked together along the cracks - which act as hinges- only by the reinforcing bars.

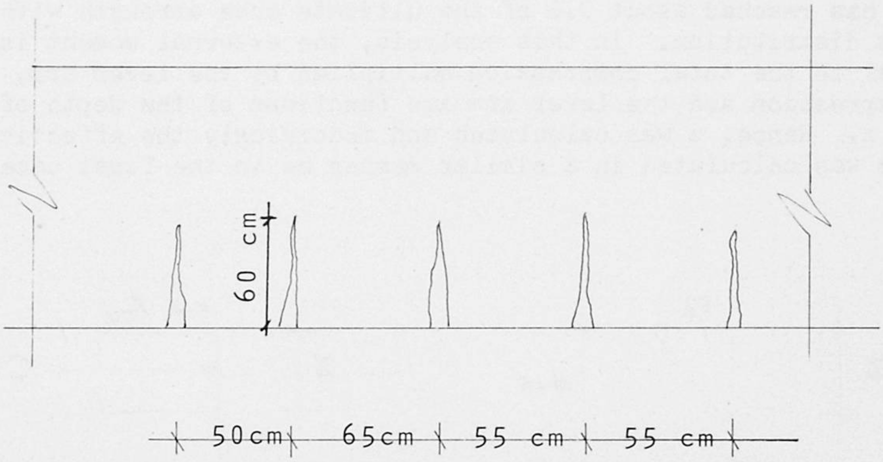


Fig. 2 Cracks At Mid Span Of Beams

2.2 Reasons For Damage

Generally in any building, damage can take place due to the action of one or more of several reasons such as overloading of any element, fires, unexpected deformations due to unknown soil conditions, accidental actions due to poor quality of construction, chemical and/or physical actions due to errors in specifications and design. However, for the building under consideration, the original design was checked and found to be safe.

The main reasons for the damages were the miss use and bad maintenance. A steel water tank of two cubic meters capacity was located on top of one of the shells. Plenty of pipe networks were also located on top of the shells. These pipes were not well connected and leakage of water and chemicals was noticed. The gutters over the valley beams, between adjacent shells, were found to be almost filled with mud which prevented proper drainage of water to take place. This mud and water added an extra load on the beams which was not taken in to account in the original design.

Due to the above mentioned reasons, the beams were cracked and the prestressing cables started to corrode. Accordingly, the effective prestressing forces were reduced considerably, followed by rupture of prestressing cables and sudden collapse.

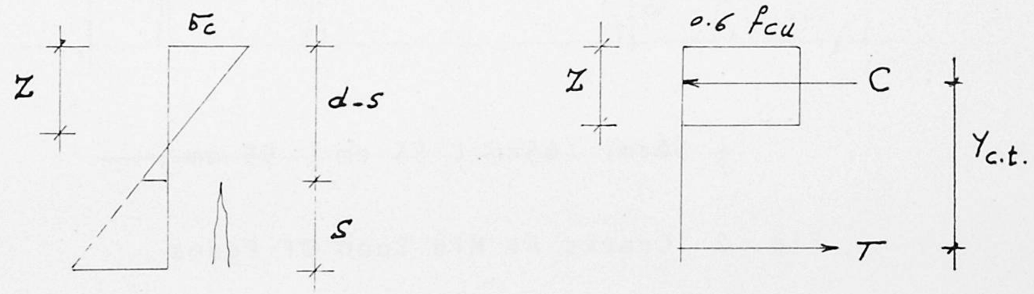
3. ANALYSIS OF THE STRUCTURAL BEHAVIOUR

It was necessary to estimate the remaining prestressing forces in the valley beams. In this respect certain bounding assumptions were made regarding the stress distribution across the critical section, i.e. section at mid span, and regarding the effective flange width to be considered in the analysis.

As far as the stress distribution is concerned, two limiting cases were considered as follows:

- In the first case, fig. 3a, the stress distribution was assumed to be linear. In this case it was assumed that the tensile stress at the level of the top end of the crack is equal to the tensile strength of the concrete which can be evaluated. The actual external moment applied on the section was calculated, i.e. it was known. Thus from first principals, the total compression was calculated which is equal to the total tension. The effective prestressing force was accordingly estimated.
- In the second case, fig. 3b, it was assumed that the compressive stress in

the concrete has reached about 0.6 of the ultimate cube strength with a non-linear stress distribution. In this analysis, the external moment is known which is equal to the total compression multiplied by the lever arm, Y_{ct}. Both the total compression and the lever arm are functions of the depth of the nutral axis, z. Hence, z was calculated and accordingly the effective prestressing force was calculated in a similar manner as in the first case.

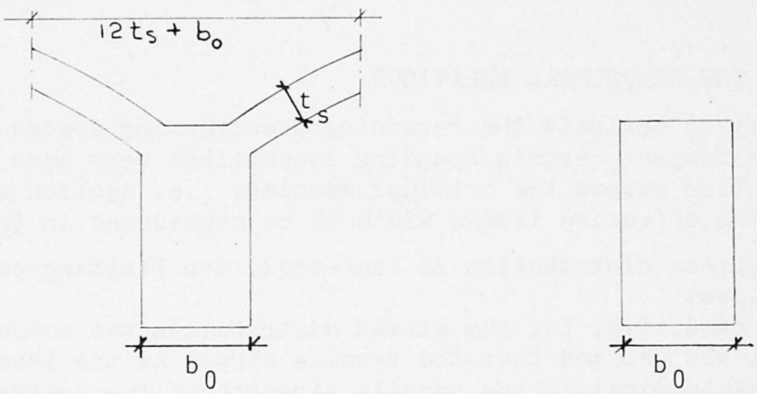


a) Linear stress distribution   b) Equivalent rectangular stress block.

Fig. 3 Assumptions Of Stress Distribution

As far as the effective flange width is concerned, two cases were considered for each stress distribution case as follows:
- The beam was considered to be as a rectangular section without any flanges acting as shown in fig.4a. This case gave the heighest value of loss of prestressing.
- The beam was considered to have an effective flange width equal to the web bredth plus twelve times the shell thickness as shown in fig. 4b.

It should be noted that the problem under consideration is not that straight forward and some engineering judjment had to be made. From the crack pattern in the valley beams together with the above mentioned calculations, it was estimated that a maximum loss of about 40% in the original prestressing force has taken place.



b) Flange width $12t_s + b_0$ a) No flange acting

Fig. 4 Assumption Of Effective Flange Width Acting

4. SYSTEM ADOPTED FOR REPAIR

4.1 Beams

Two alternative methods for strengthening the beams were considered as follows:
- The first one by using ordinary reinforced concrete in jacketing the beams as shown in fig.5. The advantage of this method was that it does not need especial equipments. However, it needs the use of shuttering and especial casting technique in order to make sure that the fresh concrete has filled the shuttering completely. It necessitated breaking of the external walls in order enable casting the columns jackets which were required to support the jacketing of the beams.

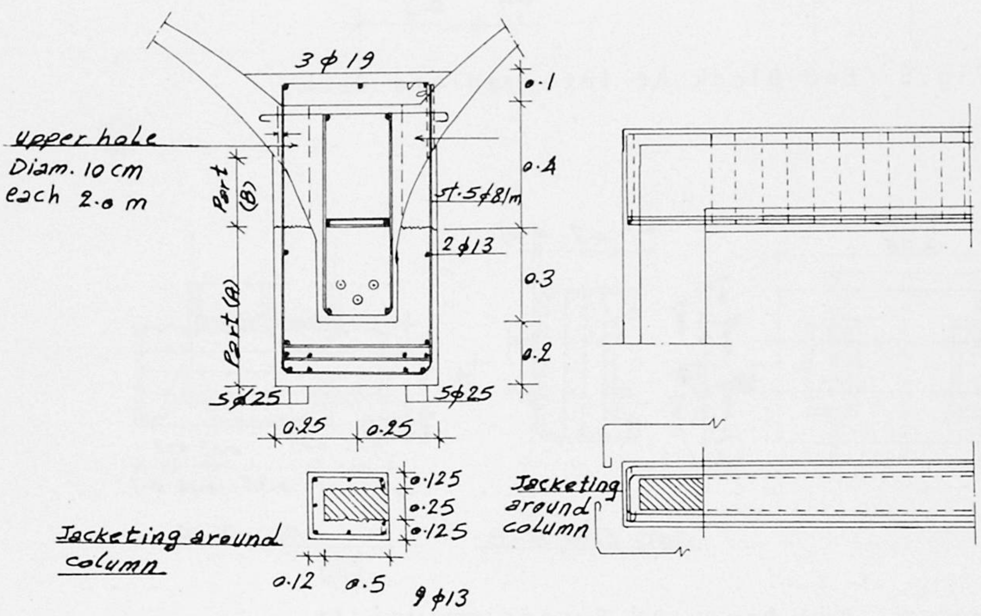


Fig. 5 First proposal for repair using ordinary reinforced concrete

- In the second method, the beams were to be strengthened by the use of external prestressing cables. These cables were to be anchord - outside the building - in precast concrete end blocks. Fig. 6 & 7 show the end blocks used for the intermediate beams and that used at the expansion joints. It should be noted that for the end blocks at expansion joints neoprene sheets were installed between the columns and the blocks in order to allow for expansion movements. Fig. 8,9&10 show the repair for the exterior beams, for the intermediate beams and for the beams at the expansion joints respectively. The advantage of this method over the first method is that it saves time, it is easy to perform, it does not add any more weight to the beams and it needs no shuttering, i.e. the repair can be carried out without the need of stopping the production of the factory. However, it needs especial prestressing equipments to be available.

It should be mentioned that in both proposed methods calculations were made for the following two limiting cases:
- The case of full old prestressing force acting.
- The case of 40% loss of old prestressing has taken place.

The second method was adopted and was carried out.

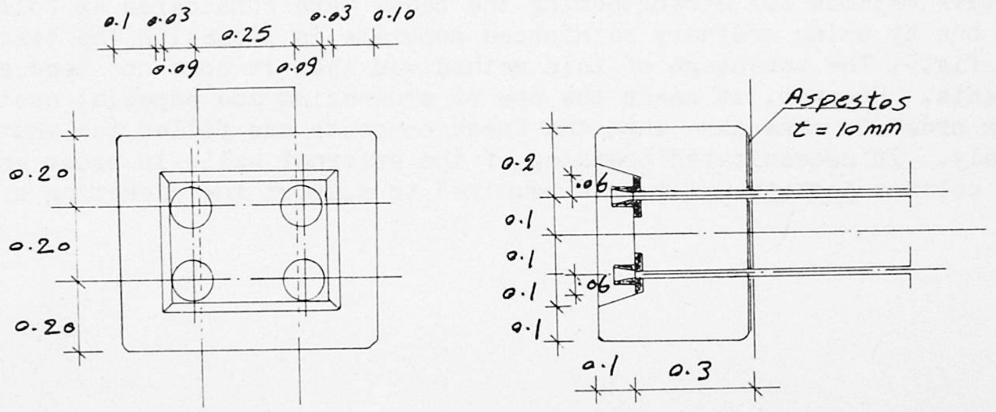


Fig.6 End Block At Intermediate Beams

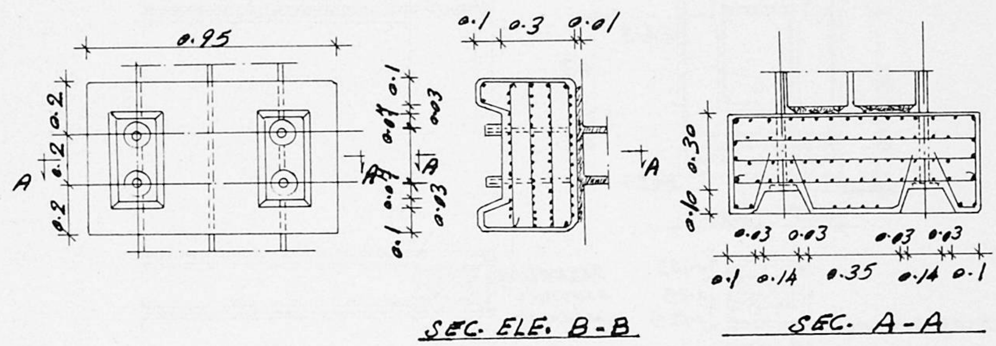


Fig.7 End Block At Expansion Joints

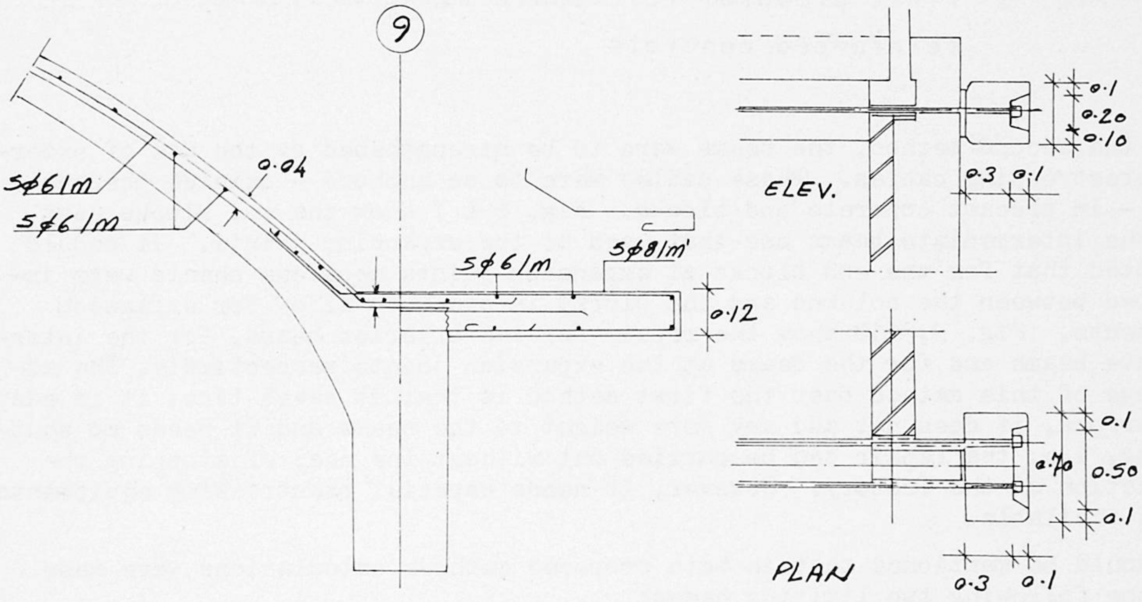


Fig.8 Repair Of Exterior Beams

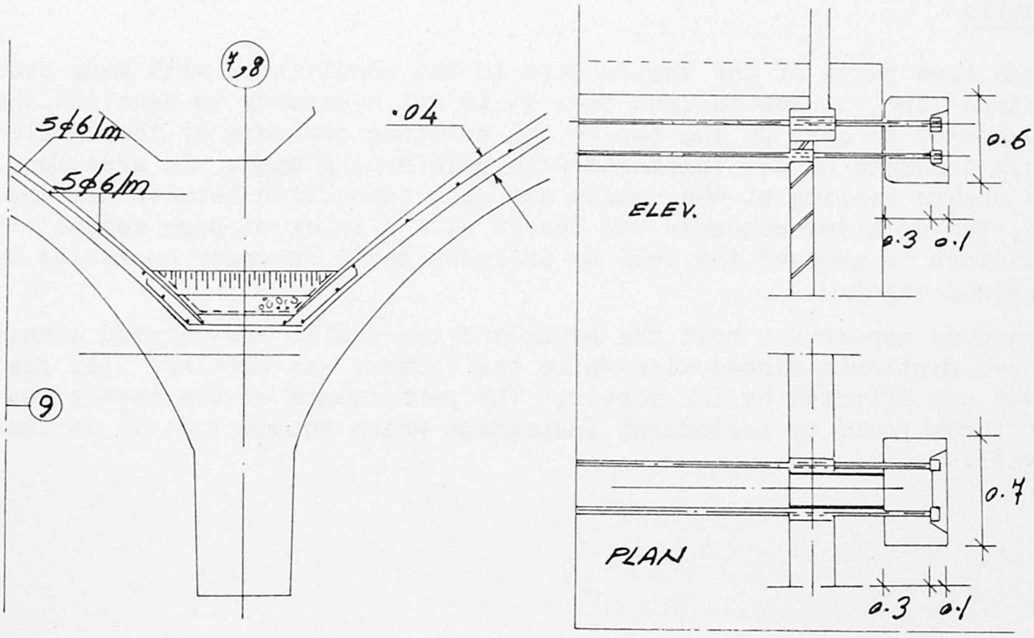


Fig.9 Repair Of Intermediate Beams.

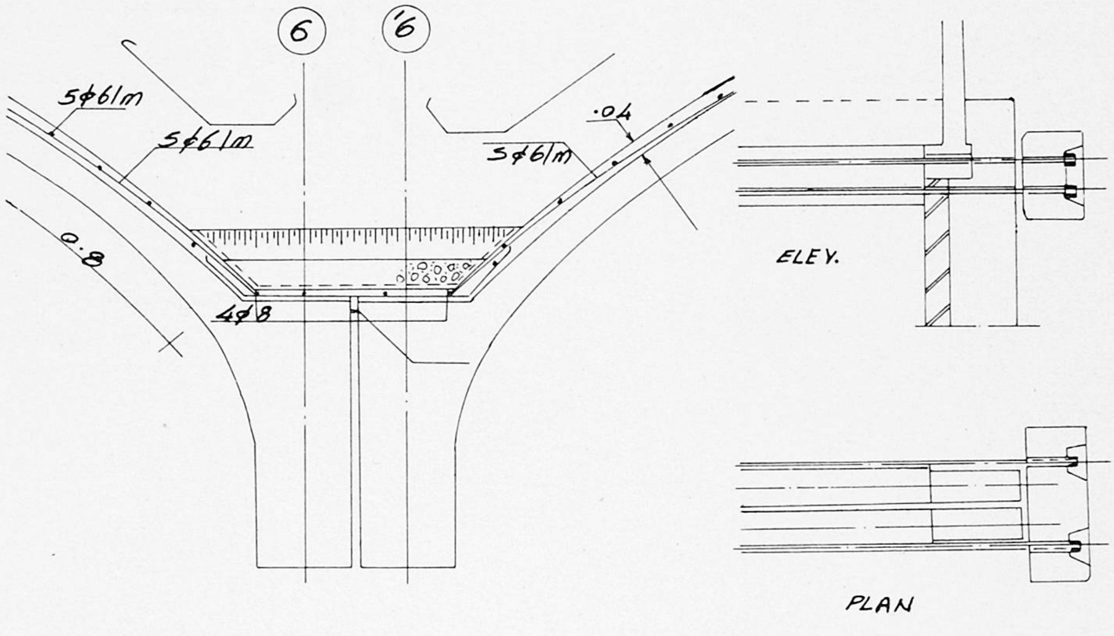


Fig.10 Repair Of Beams At Expansion Joints.

4.2 Shells

Although some parts of the shells were in bad conditions, with many cracks in both directions, it was thought that it is not necessary to demolish them. It was suggested to cast on the top on the existing concrete of the shella a layer of resin concrete of 4cm thickness with reinforcing mesh. In addition, in order to ensure sealing of the cracks and good connection between old and new concrete, the existing concrete was coated with a layer of pure resin. It was also decided to protect the roof by an epoxy resin in order to resist any water or chemical vapour.

The proposed repair for both the beams and the shells was carried according to the above mentioned discription while the factory was working, i.e. the production was not affected by the repair. The performance of the repair was recorded for three years by periodical inspection which showed that it is functioning very well.