

AN UNDERGROUND SHOPPING CENTER FIRE AND AFTER-FIRE REPAIR PROJECT

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SYNOPSIS

In this article, a fire which took place in the largest underground shopping center of Istanbul (Turkey) and its after-fire repair and strengthening project prepared by the authors are reported.

First, the structure and the fire are described. Then, after-fire surveys and the repair project are summarized. In the conclusions, general concepts related to fire effects on reinforced concrete structures are discussed.

Keywords = fire, reinforced-concrete structures, fire effects, damage classification, strengthening, repair.

1. INTRODUCTION

Today, due to increasing world population and decreasing natural resources, building durable and safe structures to withstand all sorts of risks, as well as repairing and renovating damaged structures have gained importance more than ever.

There are three types of loads which effect structures: main loads, secondary loads, and special loads. Main loads are loads which permanently or very often effect the structure (dead loads, live loads, shrinkage-creep loads, etc.). Secondary loads are loads which effect the structure less often (wind loads, snow loads, seasonal temperature changes, etc.). Special loads are loads which seldom effect the structure (earthquake loads, fire loads, critical accident loads, etc.). Fire a special load which has to be considered when structures are designed, is in essence a sudden energy (heat) discharge on the structure. It is generally quite difficult to gather authentic information on structural fires which are complex phenomena, by theoretical or experimental research work. The most straightforward way to obtain information on the structural behavior during fires is a careful inspection of structures which have undergone fires.

In the article, the authors are reporting the experience gained from a major fire event and after-fire repair project of a large and interesting reinforced concrete structure.

2. DESCRIPTION OF THE AKSARAY UNDERGROUND SHOPPING-CENTER PROJECT

The structural system of the Aksaray Underground Shopping Center together with the adjacent underground carpark and Aksaray Square viaducts have been designed by Yapı Merkezi in 1968 {1}. The 72 m x 144 m shopping center which has four main entrances was designed using a cast-in-situ reinforced concrete system and was put into service in 1973 (Fig.1).

The structural system consists of a flat slab ceiling ($d = 0.55\text{m}$) supported by 8 meter spanned columns with 3.20 meter diameter drop panels ($d = 0.85\text{m}$). The ceiling slab is separated into three monolithic masses by expansion joints along F and L axes. This slab rests on the load bearing peripheral retaining walls and beams along the expansion joints with simple supports. Due to viaduct pier footings, the foundation between A and F axes is solved with a raft system. Between F and T axes spread footings are used.

In the structure, with the exception of beams along the expansion joints which are B 300 ($f'_{cu} = 300 \text{ kgf/cm}^2$ cube strength), B 225 ($f'_{cu} = 225 \text{ kgf/cm}^2$ cube strength) concrete obtained with crushed limestone aggregates was used. The ceiling slab was designed using St IIIa ($42/55 \text{ N/mm}^2$ hot rolled) bars while the drop panels, columns, and foundations were designed using St I ($22/34 \text{ N/mm}^2$ hot rolled) bars. In practise, the contractor used St IIIb ($42/55 \text{ N/mm}^2$ cold rolled) instead of St IIIa which was not commercially available then.

3. DESCRIPTION OF THE FIRE

The shopping center fire started at 0:30 AM on Dec.25,1975 due to an electric short circuit in a shop at the HI34 module. According to the fire department report, the first squad started to pump water on the flames at 0:46 AM, but despite the efforts of several squads, the fire spread rapidly and was soon out of control. Fans were used to suck out the smoke but dense smoke and very high space prevented the squads from getting within an effective fighting distance to the flames. At 2:30 PM the fight was given up and the four main entrances were shut off with wood, canvas and sand to let the fire self-extinguish by lack of oxygen.

Meanwhile, water was hosed inside from two bored holes over the ceiling but this was not very effective. The fire, losing its initial strength after 36 hours, continued for 63 hours.

There were 3 casualties due to smoke poisoning at early hours of the fire. The property loss was estimated to be 4 million dollars.

4. THE AFTER-FIRE SURVEYS AND RESULTS

Properly designed reinforced concrete structures, even if they face a long duration fire, will not generally fail and collapse. The structure will have a good chance to get repaired. A typical example to this hypothesis is the Aksaray Underground Shopping Center fire. Despite the fact that the structure was abandoned to burn for 63 hours, it could be successfully repaired.

The determination of the most suitable and economic repair methods depends on a very meticulous investigation and evaluation of the damages caused by the fire. In reinforced concrete structure fires, the concrete spalls off, loses its strength, and its elastic modulus decreases; the reinforcement loses its strength, deforms, sags, and gets detached from concrete. In result, the reinforced concrete structure may lose its load bearing capacity partially or totally. This loss of load bearing capacity depends on the space temperatures reached during the fire and the duration of these temperatures. Two other factors which affect the degree of damage are the types of materials used and statical system of the structure.

In determining the remaining load bearing capacity of the structural system, two basic informations need to be gathered and correlated

- a) Space temperatures reached during the fire,
- b) Fire damage classification.

In the Aksaray repair project, first, maximum fire space temperatures were estimated by inspecting the fire debris and the structure's condition. After these inspections and surveys, it was concluded that the minimum space temperature was 100°C while the maximum temperature reached 800°C at certain locations (Fig 1).

Then, regions which faced space temperatures higher than 200°C were carefully examined as follows :

- The impact sound of columns were checked with a 0.500 kg hammer.
- The color of concrete was observed at the ceiling slab, drop panels and columns where concrete has spalled off.
- The areas where concrete has spalled off were sketched on the plans.
- The depth of spalled concrete was measured.
- The exposed reinforcement was surveyed (the percentage of exposed reinforcement in a module, the maximum deflection of the bars, the length of deformed portion of the bars, etc.).
- The structural and cosmetic damages of these regions were photographed (Fig.2).
- At several locations, concrete strengths were estimated using Schmidt Hammers and ultrasonic instruments. Furthermore, cores were drilled out and compression tested in the laboratories.
- Finally, St I and St IIIb bars were taken out from no-damage, light-damage, and heavy-damage areas and tension tested to determine the yield and failure stresses, and failure strains {2}.
- Based on these surveys, tests, and reports, the shopping center was damage classified (Fig.4) using the criteria given in Fig.3.

5. THE REPAIR AND STRENGTHENING PROJECT

In the structural system, the foundations, the peripheral load bearing retaining walls, and the expansion joint beams did not require any structural repair; cosmetic repair (cleaning smoke stains and perlite plastering) was sufficient.

The structural repair and strengthening measures applied on the columns, column heads, and ceiling slabs are summarized below {3}.

5.1. Column Repairs

The columns of the structure were not heavily damaged. However, 13 columns (G3, H3, L3, F4, G4, H4, I4, G5, H5, G6, I6, N7, P7) were repaired since their hammer impact sound were weak. First, the damaged concrete was chiseled and the undamaged concrete was exposed. Then, ST IV (150.150.8.8) mat reinforcement was welded on the main reinforcement and shotcrete was applied to form a jacket.

All the columns, damaged-undamaged, were brushed and cleaned from smoke and debris. Finally, the repaired and cleaned surfaces were covered with perlite plaster.

5.2. Drop Panel Repairs.

Drop panels, due to their statical functions, were not severely damaged and did not require structural strengthening. After concrete was chiseled off and the reinforcement was brushed clean, shotcrete concrete was used. Then, all the drop panels were covered with perlite plaster.

5.3. Ceiling Slab Repairs

The most important fire damage occurred at the ceiling slabs. At the I and II.degree damaged regions cosmetic repairs (cleaning the rust of the reinforcement by wire brushes, cleaning the smoke and soot from the concrete surfaces by wire brushes-acid solutions-chisels, water cure, shotcreting, and perlite plastering) were sufficient.

In the III.degree damaged regions, first, the deformed and sagged reinforcement which had lost their characteristic material properties were cut out and St IIIa reinforcements were welded in their place. Then, cosmetic repair was applied.

In the IV.degree damaged regions, besides the repair measures used for the III.degree regions, structural strengthening was required. Thus, the IV.degree damaged modules were supported with a strengthening column at their centers. The construction principle of these columns is summarized in Fig.5. Load displacement measurements taken during the construction of the HI 67 column are given in Fig.6. In the repair project, 17 strengthening columns were used at the IV.degree damaged areas.

Also, at the III. and IV.degree damaged areas, load bearing partition walls (in accordance with the architectural lay-out) were built. The topping beam of these walls were wedged with the ceiling slab to obtain a reserve strength in carrying the traffic loads over the shopping center.

6. CONCLUSIONS

The following conclusions were reached on the Aksaray Underground Shopping Center fire and its structural behavior.

- The fire could only be extinguished by limiting the supply of oxygen since inadequate precautions were taken against the fire hazard, and no fire fighting plan was available.
- The structural damage has increased since fire could not be extinguished in time and since fire risks were not fully considered in architectural details (combustible hanging ceiling, partition walls which do not extend up to the ceiling, unplastered concrete surfaces).
- The structure was able to stand up and carry the superposed traffic loads without temporary supports although it was abandoned to burn by itself for 63 hours.
- This successful fire performance can be attributed to
 - The structural system (reinforced concrete flat slab ceiling), and
 - The construction details used in the design (which enables the structure to transfer its loads uniformly and provide a reserve load bearing capacity under critical conditions).
- As the space temperatures exceeded 300°C, the concrete spalled off and the depth of this spalling increased as a function of temperature and the duration of this temperature.
- The fire exposed concrete practically retained its original strength characteristics beneath a 2.5~5 cm damaged surface layer.
- The reduction of strength observed in the St I reinforcement did not have a practical significance. In comparison to undamaged region samples, the reinforcements of the most heavily damaged regions showed a 10 % decrease in yielding levels, and a 2 % decrease in failure strengths and the failure strains reduced by 7 %. Thus, characteristic values (obtained with a 95 % probability) of the damaged St I reinforcements stayed within their norm values.
- The reduction of strength observed in the St IIIb reinforcement, on the other hand, was rather significant. In comparison to undamaged region samples, the reinforcements of the most heavily damaged regions showed a 21 % decrease in yielding levels, a 23 % decrease in failure strengths, and the failure strains increased by 23 %. The damaged St IIIb characteristic values obtained with a 95 % probability were 40 % less in yield levels and 22% less in failure strengths than their norm values while the failure strains remained within the norm limits. Thus, in the statical calculations of the repair project it was assumed that the St IIIb reinforcement in the damaged areas will behave as St I steel.
- From the Civil Engineering perspective, "fire is a load". Fire risk of structures, is increasing each day as the technology advances. Therefore, when the structural systems of buildings are designed, fire "loads" and risks, similar to the risk calculation concepts of earthquake engineering, should be considered. This concept which should be included in building codes is supported by the similarity between "fire" and "earthquake" loads which are "sudden energy (heat or kinetic energy) discharges on the structure".

After the structural repairs were completed the mechanical fire safety precautions (which were also included in the original design) were taken and the shopping center was opened to service in October 1980 (Fig.7).

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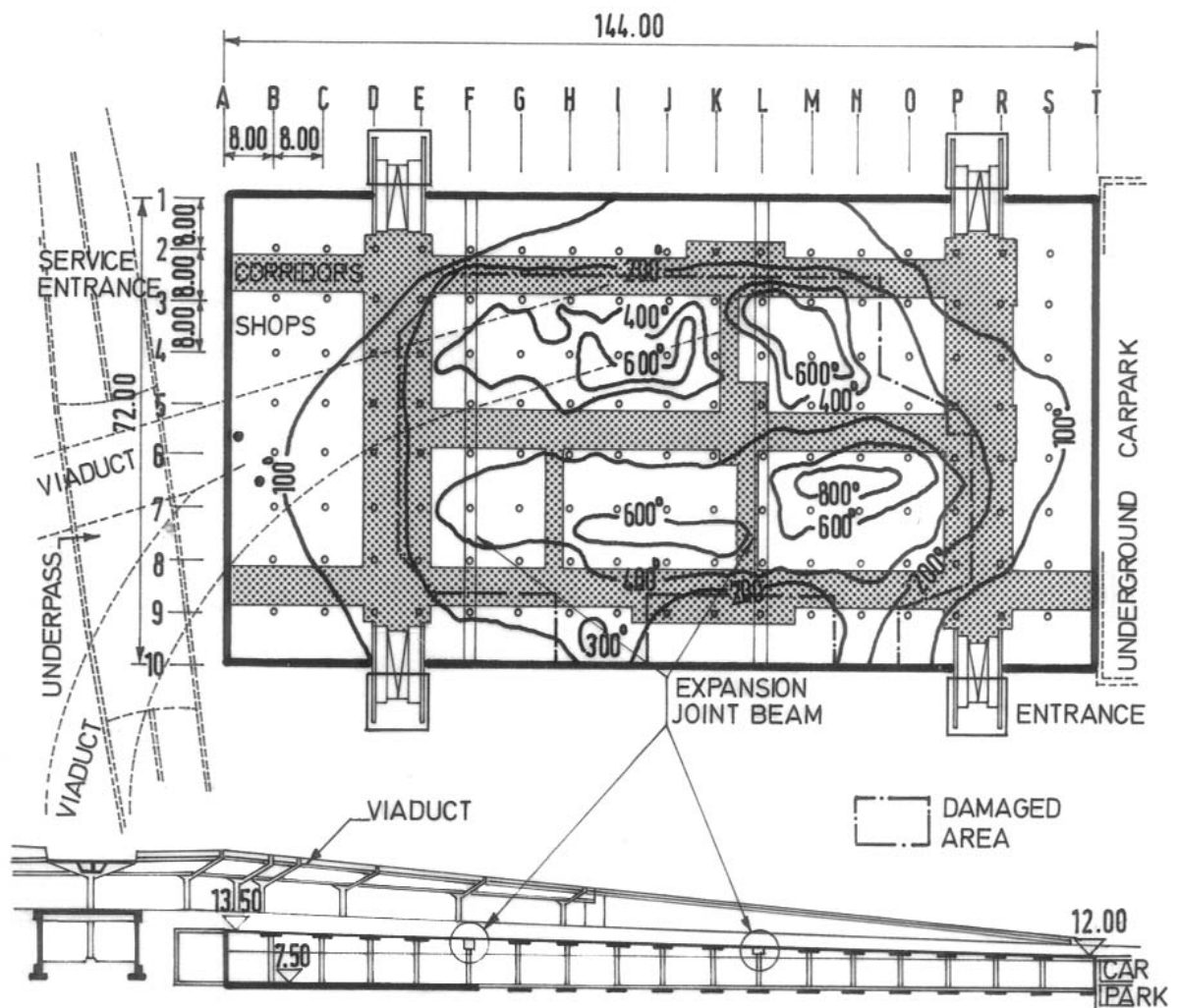


Fig. 1 -AKSARAY UNDERGROUND SHOPPING CENTER PLAN AND FIRE SPACE ISOTHERMS

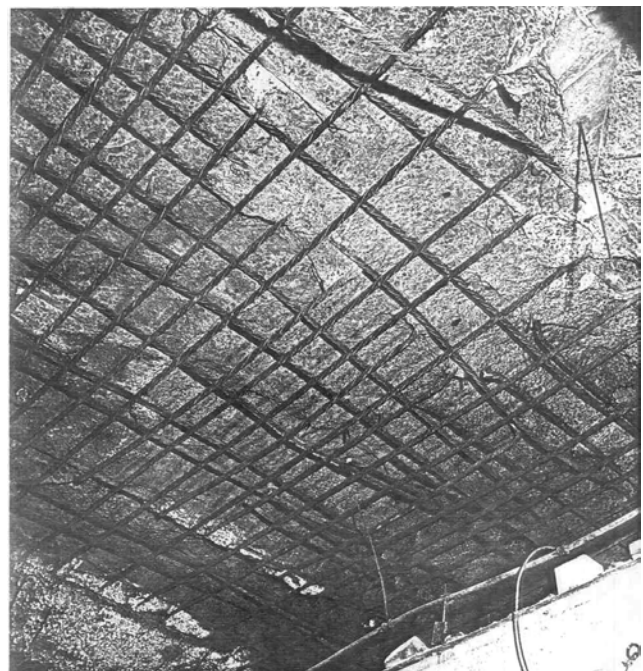
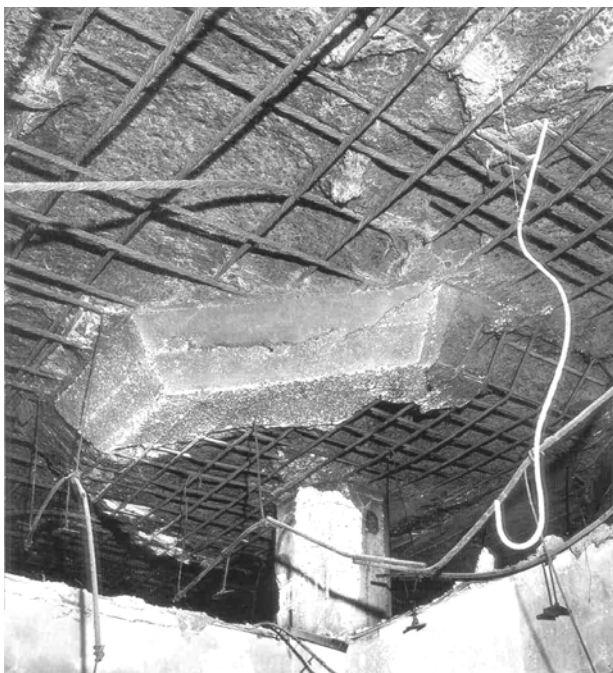


Fig. 2 -STRUCTURAL DAMAGE PHOTOS

DAMAGE CLASSIFICATION	SPALLED CONCRETE AREA	SPALLED CONCRETE DEPTH	HAMMER SOUND	PERCENTAGE OF DEFORMED REINFORCEMENT	CHANGE OF MECHANICAL PROPERTIES OF REINFORCEMENT	FIRE SPACE TEMPERATURES	REPAIR DECISION
	m ²	cm	-	%	%	°C	-
NO DAMAGE	-	-	-	-	-	< 200	NO REPAIR
I. DEGREE DAMAGE	< 10	< 3	SOUND	-	< 5	< 400	NO REPAIR
II. DEGREE DAMAGE	< 60	< 7	SOUND	-	< 10	< 400	COSMETIC REPAIR
III. DEGREE DAMAGE	> 60	< 12	WEAK	10	< 20	< 600	STRUCTURAL REPAIR
IV. DEGREE DAMAGE	> 60	< 16	WEAK	10	> 20	< 800	STRUCTURAL REPAIR AND STRENGTHENING

Fig. 3 - FIRE DAMAGE CLASSIFICATION CRITERIA

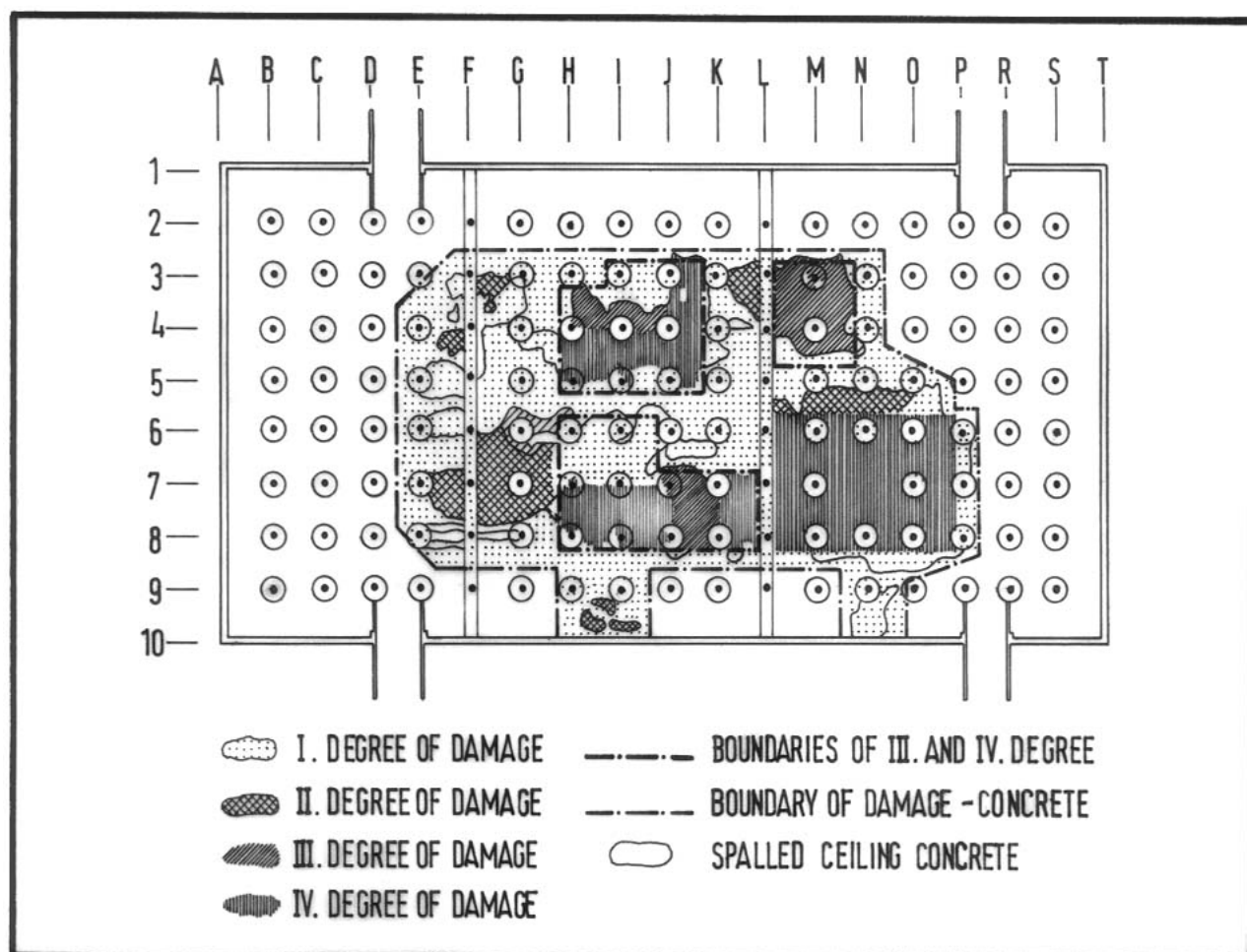


Fig. 4 - DEGREE OF DAMAGE CLASSIFICATION

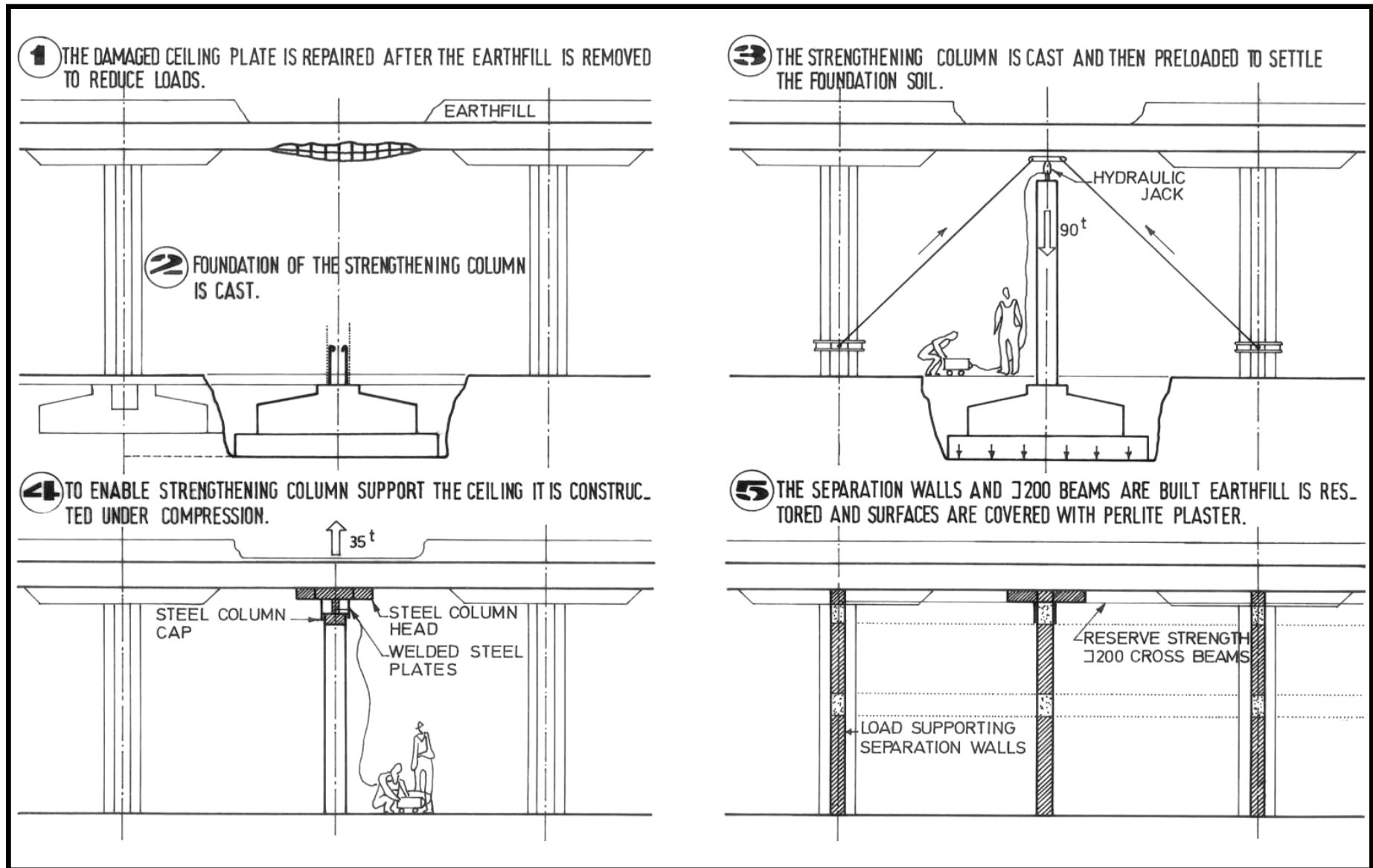


Fig.5 - CONSTRUCTION SEQUENCE OF THE STRENGTHENING COLUMN

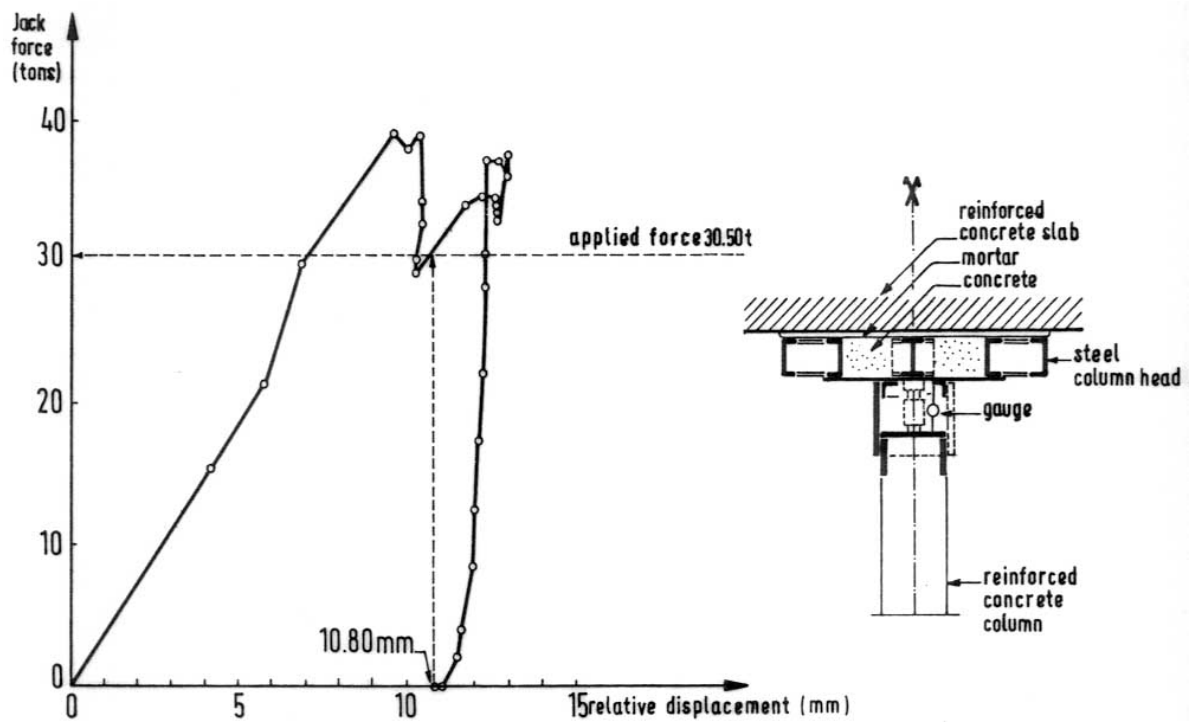


Fig.6 - STRENGTHENING COLUMN CONSTRUCTION UNDER COMPRESSION



Fig.7 - THE UNDERGROUND SHOPPING CENTER JUST BEFORE OPENING TO SERVICE