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# LOAD TEST ON THE FIRE GUTTED NASACO BUILDING IN DAR ES SALAAM

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## ABSTRACT

*For the purpose of saving costs related to establishing new building sites and construction, the necessity of preserving the existing architectural image and natural or man-made disasters are among the many factors contributing to the importance of re-evaluating doubted existing structures with the aim of increasing their service life. The problems affecting these structures include the nature of the ageing process of the construction materials, their quality control during construction, effects from natural and man-made disasters on the behaviour of the structures, etc. The analytical study on these problems is still underway and even the most up-to-date state-of-the-art on this subject can not guarantee a reliable re-evaluation relying only on mathematical models. Hence, non-destructive insitu test known as load test seems to be one of the most effective tool for the assessment of such concrete structures with regard to strength reliability.*

*This paper presents the load test performed to a fire-gutted multi-storey concrete structure, the results of which have shown that the strength of the structure is still adequate and needs only strengthening and repair.*

## INTRODUCTION

The load test is usually performed on completed concrete structures when there is reasonable doubt on the adequacy of their strength. In case the structure shows doubtful deterioration during its service life, in particular after having been subjected to fire damages, loads; such as repeated dynamic loads on bridges and large store houses, chemical attacks, earthquake, etc. such structures have to be analysed to make sure that they still have reliable strength and can function well and safely. There are different methods used to evaluate the conditions of existing structures as shown in table 1. Most of the tests listed in table 1 need sophisticated equipment to enable the test to be carried out. In the following sections the in-situ load test performed to the fire gutted NASACO building in Dar es Salaam is discussed. The presentation starts with review of the fire gutted building and the effects of fire on the concrete structures, the load test principles and processes involved, results, conclusion and recommendations

## EFFECTS OF FIRE ON CONCRETE STRUCTURES

Concrete is a porous substance bound together by water-containing crystals. The binding material can decompose if heated to high temperatures resulting into loss of strength. The loss of moisture causes shrinkage to the concrete, and the rising of temperature causes the aggregates to expand leading to cracking and spalling of the concrete.

Table1: Tests applied to structures

| TEST | METHOD USED | MAIN RESULTS |
|---|---|---|
| Ultrasonic pulse velocity (concrete) | Determination of ultrasonic pulse propagation velocity | Young Modulus, Strength, Crack existence |
| X and Gama Rays (concrete and steel) | Radiographs | Dimension and position of reinforcement, Cavities in concrete |
| Electrical Methods (concrete) | Determination of overall capacitance or electrical resistivity | Moisture content, Thickness of pavement |
| Dynamometer (steel) | Determination of magnetic permeability | Reinforcement tension |
| Thermic methods (concrete) | Determination of maturity | Strength |
| Galvanic cell (steel) | Measurement of an electrical potential | Corrosion areas in reinforcement |
| Magnetometer (steel) | Measurement of magnetic field | Position of reinforcement |
| Acoustic methods (concrete) | Determination of the intensity of an acoustic emission | Estimation of ultimate load, Crack existence |
| Sclerometer (concrete) | Determination of the surface hardness (rebound number) | Strength |
| Penetration (concrete) | Determination of the resistance to penetration of a probe | Strength |
| Pull-out (concrete) | Determination of the pull-out resistance | Strength |
| Cores (concrete) | Determination of the compression resistance | Strength |
| Load Test (structure) | Determination of tensions and deflections | Ultimate load, Behaviour under service conditions |
| Dynamic Test (Structure) | Determination of the structure's response to dynamic excitation | Dynamic characteristics |

High temperatures cause loss of strength of steel reinforcements due to the reduction of the amount of carbon content. It is known that steel with carbon content in the range 0.07% to 0.15% is suitable for use as wire nails, rods, rivets, fencing wires, binding wires, mattress wire and hot rolled strips for general use purposes. From 0.15% to 0.25% carbon content, the steel is suitable for general structural steel; i.e. mild and high yield structural steels.

Fire resistance of concrete structures depends mainly on the thickness of the structural members, the provided concrete cover, duration of fire attack on the structure and type of aggregates used.

## Factors influencing Fire Resistance

### Thickness of structural member:

BS 8110 provides minimum thickness necessary for various structural members to meet the specified fire resistance in hours. The values are shown in Table 2 below.

Table 2: Minimum dimensions of reinforced concrete members for fire resistance [3]

| Fire resistance | Minimum beam width (b) | Rib width (b) | Minimum thickness of floors (b) | Column width (b) | | | Minimum wall thickness | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Fully exposed | 50% exposed | One face exposed | $\rho<0.4\%$ | $0.4\%<\rho<1\%$ | $\rho>1\%$ |
| h | mm | mm | mm | mm | mm | mm | mm | mm | mm |
| 0.5 | 200 | 125 | 75 | 150 | 125 | 100 | 150 | 100 | 75 |
| 1 | 200 | 125 | 95 | 200 | 160 | 120 | 150 | 120 | 75 |
| 1.5 | 200 | 125 | 110 | 250 | 200 | 140 | 175 | 140 | 100 |
| 2 | 200 | 125 | 125 | 300 | 200 | 160 | - | 160 | 100 |
| 3 | 240 | 150 | 150 | 400 | 300 | 200 | - | 200 | 150 |
| 4 | 280 | 175 | 170 | 450 | 350 | 240 | - | 240 | 180 |
| $\rho$ is the area of steel relative to that of concrete. | | | | | | | | | |

### Concrete cover:

Concrete cover has to provide protection to the reinforcement from fire and environmental attack. The concrete cover described in this context refers to the distance between the nearest heated face of the concrete and the surface of the main reinforcement. The recommended concrete covers are shown in Table 3.

## Concrete and Steel

### (a) Structural concrete:

The strength of concrete varies with temperature changes. The strength of

Table3: Nominal cover to all reinforcement (including links) to meet specified periods of fire resistance [3]

| Fire resistance | Nominal cover | | | | | | |
|---|---|---|---|---|---|---|---|
| | Beams | | Floors | | Ribs | | Columns |
| | Simply supported | Continuous | Simply supported | Continuous | Simply supported | Continuous | |
| h | mm | mm | mm | mm | mm | mm | mm |
| 0.5 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| 1 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| 1.5 | 20 | 20 | 25 | 20 | 35 | 20 | 20 |
| 2 | 40 | 30 | 35 | 25 | 45 | 35 | 25 |
| 3 | 60 | 40 | 45 | 35 | 55 | 45 | 25 |
| 4 | 70 | 50 | 55 | 45 | 65 | 55 | 25 |
| Cases that are bold require attention to the additional measures necessary to reduce the risk of spalling (BS 8110: Part 2) | | | | | | | |

dense aggregate concrete decreases when the temperature reaches 350°C, while for lightweight concrete its strength decreases when temperature reaches 500°C. Figure 1 illustrates the variation of concrete strength with temperature.

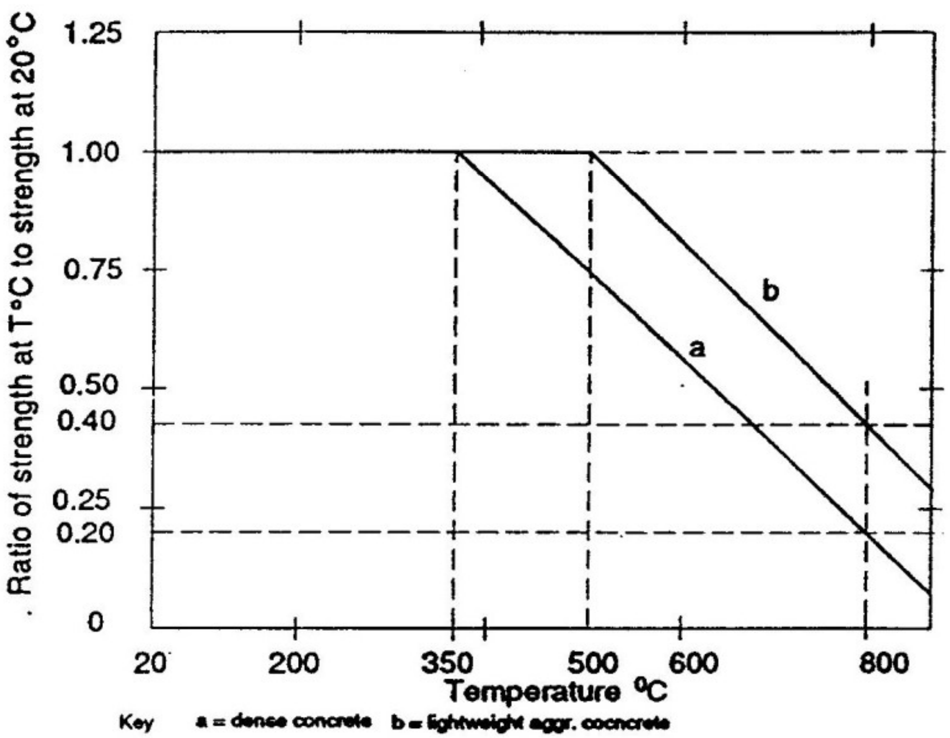


**Fig. 1 Design curves for variation of concrete strength with temperature [3]**

**(b) Stuctural steel**

Structural steel used is either hot-rolled or cold worked conditions. The use of structural steel in concrete enables lighter structures to be built by using relatively smaller sized members which provide adequate strength, stability and durability. Steel reinforcement is used in concrete for the following purposes[1];

- To take the tensile stresses in concrete beams or slabs
- To withstand shear stresses in beams which are greatest near the supports. These give rise to complementary tensile stresses in such regions which require the use of additional reinforcement -either in the form of stirrups or bent-up bars.
- To carry a proportion of the compressive stresses and to withstand tensile stresses which may arise due to eccentric loading, as in columns.
- Reinforcement may be used near the surface of mass concrete structures to control cracking due to drying or carbonation shrinkage.
- In some cases, secondary reinforcement is used to prevent spalling of concrete surface due to fire, etc.

The structural steel will continue to serve the above purposes if it is safe from chemical, physical and fire attacks. But when steel is heated to a certain temperature level, it undergoes changes in its chemical and physical properties. In BS 8110, it is stated that reinforcement steel changes its properties after reaching 300 $^0$C while prestressing wires or strands change just at 150 $^0$C temperature. For example, the strength of structural steel becomes 50% of that at 20 $^0$C after reaching just above 550 $^0$C for reinforcing steel, and 400 $^0$C for prestressing wires or strands. The said behaviour is illustrated in figure 2.

## THE FIRE GUTTED NASACO BUILDING

Construction of NASACO headquarters building was completed in 1985 and on 17th August 1995, the building was gutted by fire. All floors of the building were attacked, and materials which are susceptible to fire were seriously burnt although the structural frame remains standing to-date. The fire was accelerated by plastic shading materials and timber which was mainly used for partition walls. Observations on the burnt building shows that most of the affected areas especially slabs and beams have their plaster or concrete cover or both fallen down. Some parts of the concrete have spalling pattern due to expansion of the heated steel reinforcement.

TANconsult, in association with Cost-Consult, provided NASACO with a preliminary assessment report in September 1995 on the fire damage.

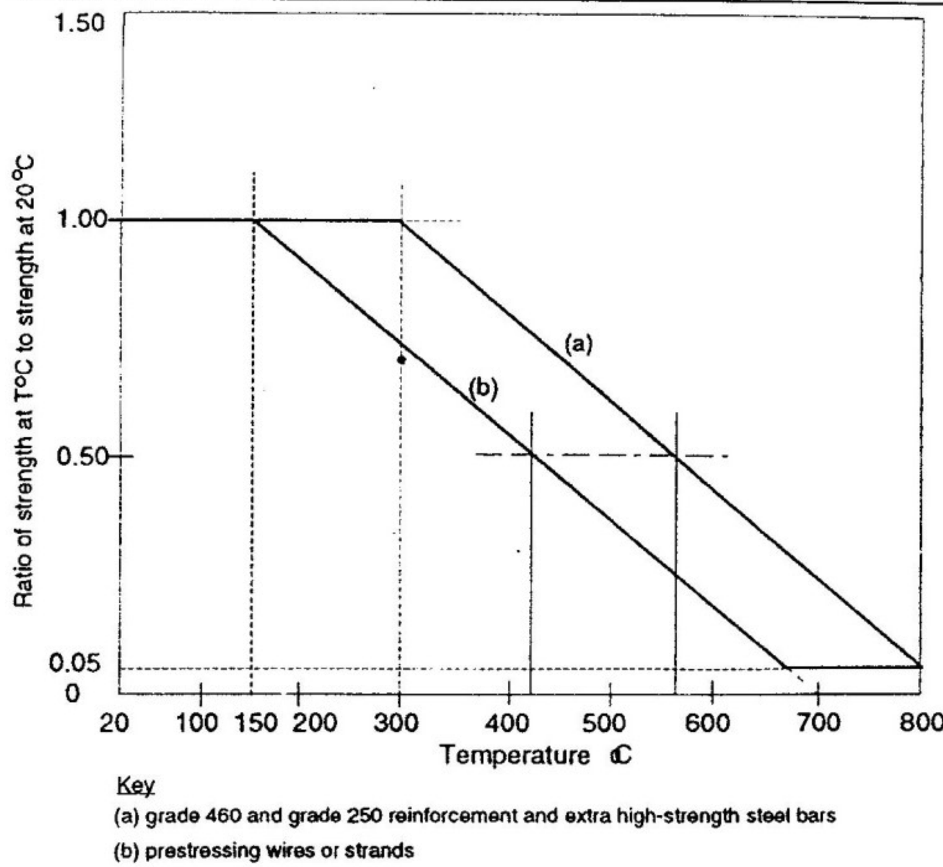


**Fig. 2 Design curves for variation of steel strength or yield stress with temperature [3]**

The structure was then tested in September 1995 by Mott MacDonald Company. The tests included core drilling, rebound hammer, and ultrasonic impulse test. All tests showed that the structure can be repaired. Fire damages to the structure were classified as 1, 2, 3 and 4. If the structural member falls in class 4, it is fit for demolition, otherwise it is suitable for repair or strengthening[**2**]. The elastic behaviour of the structure was not assessed at all. Hence the load test had to be carried out.

## THE LOAD TEST

The load test is carried out on structures which are older than two months or 56 days [3]. Since NASACO building is over 10 years old, the load test is suitable for evaluating the suitability of the fire gutted building. The objective of performing the load test in this context is to assess the strength of the structure and commend as to whether the building is still strong and therefore needs no repair , strengthening, or otherwise.

The load test is done according to specifications and procedure given in BS 8110; 1985; Parts 1 and 2 [3]. The required load for subjecting the structure into the test is one and a quarter times the superimposed load during the design. In this case the superimposed load was 5 $kN/m^2$ which then yielded 6.25 $kN/m^2$. The test procedure involves taking levels at predetermined points, then loading the structure with the prescribed load value and leave the loaded structure for 24 hours. After 24 hours, levels at the respective points are taken and then the structure is off-loaded and left to relieve for other 24 hours. On completion of the later 24 hours, levels are finally taken again. If within 24 hours of the removal of the load, the structure does not show a recovery of at least 75% of the maximum deflection shown during 24 hours under-load, the test has to be repeated. If during the test, or upon removal of the load, the structure shows signs of weakness, undue deflection or faulty construction, it should be reconstructed or strengthened.

**Spot Levels Before loading**

The test area was selected to be the first floor on the South-West of the Building. The chosen area and its respective points from which the spot levels were taken was between grids D, E, and F in longitudinal direction and grids 11 - 14 across the building. This area is shown in Figure 3. Out of the six slab panels which were selected for the test, two had their plaster fallen down due to the fire effect. The levelling instrument used was an automatic level Ni3 with a parallel-plate micrometer having an accuracy of ±0.0001m. The reading error can be estimated at ±0.0002m. A total number of 190 points were located and their levels taken. The surveying results can be seen in reference [4].

**Loading**

In order to get a uniformly distributed load, sand load was chosen for the purpose. For the six slab panels, a total number of 120 tonnes of sand was required to obtain the 6.25 $kN/m^2$. To ease the loading and off-loading processes, the sand had to be filled in plastic bags. Each bag was filled with 50kg of sand, then closed up. To avoid impact loading effect to the slab, bags were laid down gently. Both the filling of the sand in the sacks and the laying down were monitored to make sure that the bags had the required weight of sand and the laying down was consistently gentle.

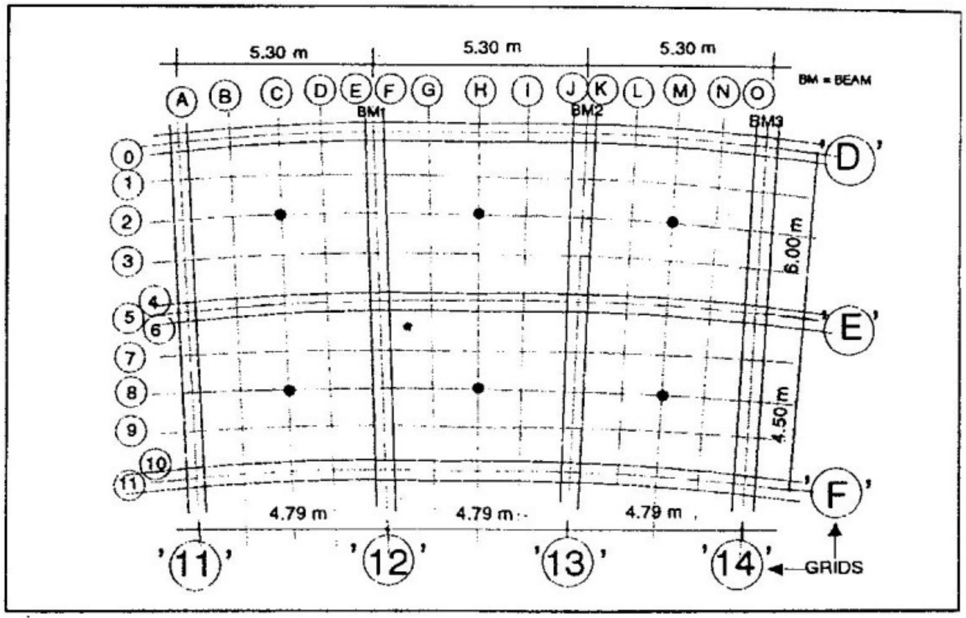


**Fig. 3 Area for Load Test and the Measured Points**

### Levelling after 24 hours under-load

After 24 hours from finishing the loading process, the spot levels were taken again for the purpose of determining the deflection between no-load and under-load conditions. The same instrument stated in 6.1 was used to take levels at the prescribed points. Results are shown in reference [4]. Then off-loading followed immediately after taking the spot levels. After that the structure was left to relieve for another 24 hours.

### Levelling after 24 hours from off-loading

After 24 hours, the spot levels were again taken in order to determine the amount of recovery from deflected shape due to the prescribed load. The same levelling instrument stated in 2.1 was used to take levels at the respective points. Results are shown in reference [4].

### Deflection from structural analysis

Slab S3 shown in figure 4 was been selected because of its location in which reasonable elastic deflection can be obtained due to its end conditions. The elastic deflection for slab or beam under loading conditions is given by the equation:

$$\delta = \frac{5}{48EI}L^2 M_{span} - \frac{1}{96EI}L^2 [M_A + M_B] \qquad (1)$$

where $\delta$ = deflection in mm, $E = 24\ kN/mm^2$ for $f_{cu} = 20\ N/mm^2$, $I = bd^3/12 = 281.25 \times 106\ mm^4$ for a 150mm slab.

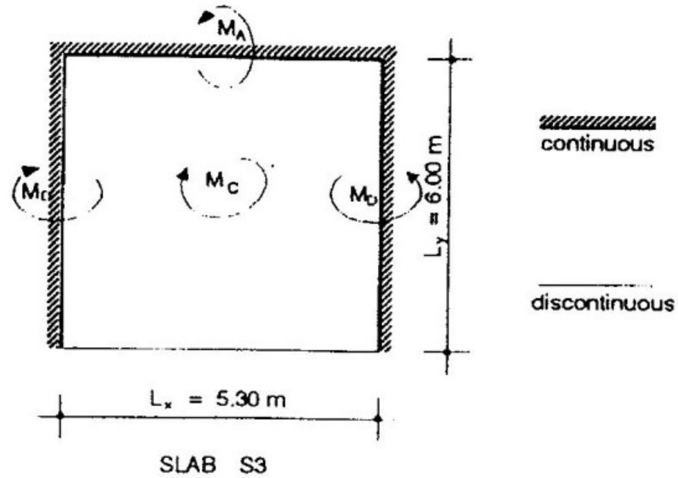


**Fig. 4 Floor Slab Moments**

The subscriptions to the moments (M) are based on the points of consideration given in Figure 4. The assumed design load of the slab was $16.26\ kN/m^2$. From BS 8110 : 1985 Part 1, the bending moment coefficients for a rectangular slab panel, supported on four sides with provision for torsion at corners with **one short edge discontinuous** and $l_y/l_x = 1.13$, are as follows: $\beta_{syA} = -0.037$, $\beta_{syC} = +0.028$, $\beta_{sxD} = -0.045$ and $\beta_{sxC} = +0.037$. With L = 5.300 m, the following moments were obtained; thus, $M_A = -16.90$ kN.m, $M_{cy} = +12.79$ kN.m, $M_{cx} = +16.90$kN.m and $M_D = -20.55$kN.m. Therefore upon substitution into equation (1) above, the elastic deflection is 5.54mm.

## RESULTS AND ANALYSIS

### Results

Figure 5 shows the points which were significant for the assessment of deflection of the slab. Spot levels of the points of each slab panel and the respective beams were taken three times: before loading, after 24 hours under-load and after 24 hours of off-load. All levels are based on an assumed reduced level of 20.0000 m above mean sea level. The Temporary Bench Mark was a steel pipe stem for stairs opening to the

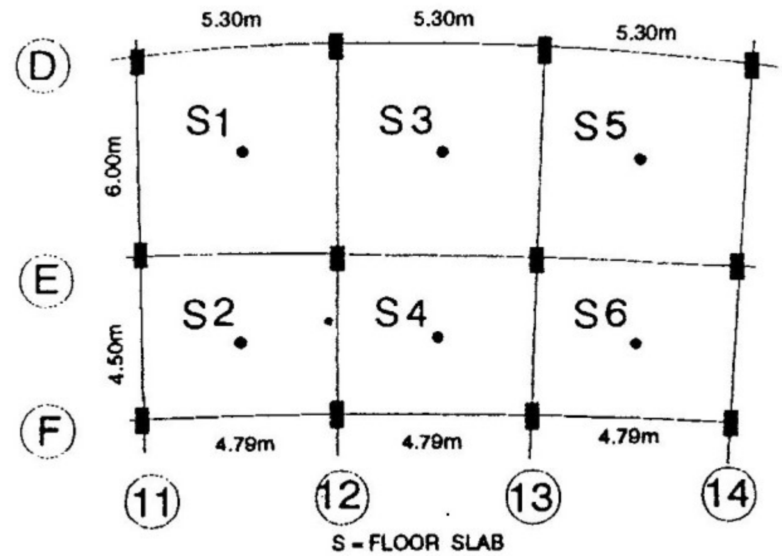


**Fig. 5 Selected Central Points**

first floor[top centre of the pipe]. Table 4 shows the obtained results for central points for each slab panel.

## Observations

For appropriate deflection pattern, the structural member deflects from zero to a certain value while under-load, then after off-loading, it goes through a recovery process. This pattern is shown in Figure 6 where by the deflection of the selected central points has been presented.

**Table 4:Deflection of selected points**

| Panel | Point | Deflection in mm | | | | Remarks |
|---|---|---|---|---|---|---|
| | | Before loading | 24 hrs under-load | 24 hrs after off-load | Recovery %age | |
| S1 | C2 | 0.00 | 1.10 | 0.40 | 64% | All deflections are smaller than the anticipated elastic ones. |
| S2 | C8 | 0.00 | 1.30 | 0.70 | 46% | |
| S3 | K2 | 0.00 | 1.10 | 0.20 | 82% | |
| S4 | H8 | 0.00 | 1.50 | 1.30 | 13% | |
| S5 | M2 | 0.00 | 1.80 | 0.90 | 50% | |
| S6 | M9 | 0.00 | 1.20 | 0.50 | 58% | |

## Conclusions

For all observed deflections [ref. Table 4 and [4], there is no single

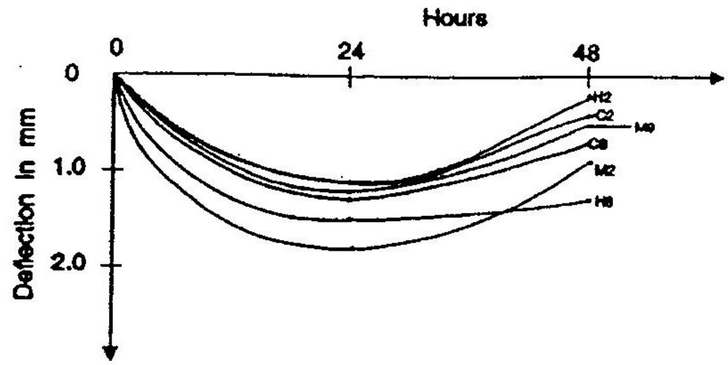


**Fig. 6 Appropriate deflection pattern**

result which is higher than the calculated elastic deflection of 5.54 mm. The recovery percentage is not significant since the deflection is very small. It is difficult to assume that the temperature reached more than 300 °C because of the type of the fire flammable materials which couldnt be still existing at such a temperature. Therefore, the main problem was expansion of the steel reinforcement causing spalling and falling down of cement plaster and concrete cover at some points.

## RECOMMENDATIONS

The obtained results show that the structure is still strong because even the expected elastic deflection was not reached. Therefore, it is recommended that

- The structure needs repair and strengthening

- The method of strengthening should include pressure pumping of the concrete, crack injection and crack sealing.

- The methods deemed in the report of the previous consultant report have to be implemented [2].

- Due to the nature of the work to be done in restoring back the strength and integrity of the fire gutted NASACO Building, a well qualified, equipped and experienced CONTRACTOR need to be commissioned to carry-out the job under close supervision of a reputable structural engineer.

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