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COLLAPSE OF AN UNDER-CONSTRUCTION TEXTILE FACTORY BUILDING

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SUMMARY

The paper presents the results of an investigation concerning the failure of a segment of an under-construction reinforced concrete roof of a textile factory building which had collapsed during casting. When the collapse of the roof took place, concreting of an area of about 1700 m^2, out of a total of 3586 m^2 area of the segment, was completed and steel binding and formwork construction of the whole segment was almost done. The segment of roof slab that collapsed was 68.4 m long in the East-West direction with a downward slope of 1%. The failure of the roof was followed by collapse of the formwork of other areas where concreting work was not taking place. Consequently, all the 74 columns and most of the footings of the whole segment also underwent damage. Although the reinforcement bindings of the inverted beams were complete at the time of casting the slabs, none of the inverted beams were cast during the period when slab casting was in progress. This resulted in the casting of a vast area of slab resting on poor quality bamboo props. Casting of inverted beams after completion of respective slab casting would have added to the overall stiffness of the slab-beam system. In this paper, relevant facts have been accumulated, critically studied and analysed in order to achieve the primary aim of understanding the causes of the failure. It has been gathered that the collapse took place as a result of faulty formwork, erroneous construction sequence and deficient structural system.

INTRODUCTION

A part plan of the Spinning Department consisting of the collapsed segment of the textile factory is shown in Fig. 1. This consists of columns spaced at 4.7 m spacing in the North-South direction and at 9.2 to 15.22 m spacing in the East-West direction allowing large free areas for the proposed use. On day 1 and day 3, the casting of the roof of Spinning Department between rows 19 and 23 was completed (Fig. 1). Then on day 6 the casting of roof slab resumed from row 23 and by noon that day it was completed upto the 24th row. While the casting operation was in progress in the afternoon and was within halfway between row 24 and 25, all on a sudden all the

concreting work done so far from day 1 to the afternoon of day 6 collapsed with a terrible sound and most of the roof was on the ground in no time. Figure 1 also shows the area E (shown cross-hatched) towards which the collapse ultimately propagated with respect to the part plan of the factory building where construction work was taking place from day 1. The arrows show approximately the inclination of the columns after failure. While Fig. 2a shows the overall condition of the working site 3 days after collapse, Figs. 2b, 2c and 2d give a closer view of the collapsed construction where casting took place on the day of collapse, 3-5 days earlier and where formwork as well as reinforcement binding was completed on the day of collapse. It is to be noted here that during the collapse of the roof, all the adjoining columns also sustained damage. This happened due to the fact that at the time of collapse steel binding of other portions of the roof, where concreting was not taking place, and all the inverted beams was almost complete. Figure 3 shows such a portion of the roof where reinforcement of roof slab and inverted beams attached to the columns can be seen. It is apparent from the figure that after the failure of the formwork even in the regions where concreting was not taking place, columns were overstressed by the hanging reinforcement of the slab and beams resulting in the damage of the columns and some footings. Whereas the structural design as well as structural system of the textile factory building was also checked, albeit in less detail, the formwork was studied in great detail from its design to erection in an effort to primarily determine the cause of the collapse of the factory building, as failure took place at a time when structural elements were not supposed to carry loads [1].

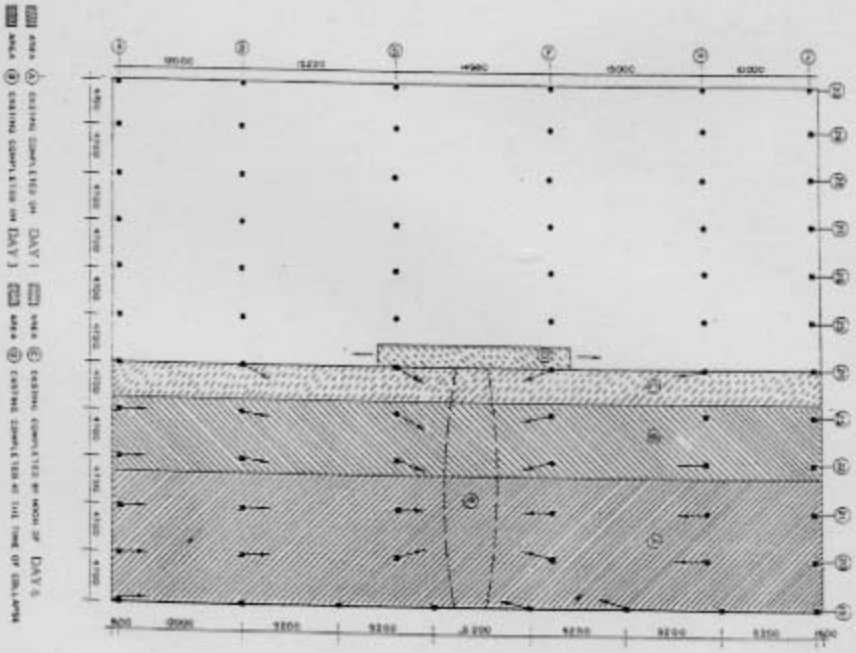


Fig. 1 Part plan of the factory building showing the collapsed area

(a)

(b)

(c)

(d)

Fig. 2 (a) General view of the collapsed construction site, (b) collapsed roof where casting took place on the day of collapse, (c) collapsed roof where casting had taken place earlier, and (d) collapsed roof where formwork and reinforcement binding was completed on the day of collapse

ASSESSMENT OF THE CONDITIONS OF STRUCTURAL ELEMENTS

The conditions of structural elements, such as slabs, beams, columns and footings, etc. were assessed. The structural elements around the collapsed area as well as in other adjoining areas were surveyed. Damaged columns in and around the collapsed area (Figs. 4a and 4b), movement of footing beneath collapsed column (Fig. 4c), improper casting sequence of inverted roof beams (Fig. 2c), and roof slab with closely situated top and bottom bars (Fig. 5) were noticed.

CAUSES BEHIND THE COLLAPSE OF THE STRUCTURE

Faulty formwork

In this paper the term "formwork" includes the total system of support for the freshly placed concrete - form sheathing plus all supporting members, hardware, and necessary bracing. Formwork for the construction of the factory building consisted of a scaffolding made of bamboo props and timber rafters and planks. This fabrication supported a concrete "form" with plain steel sheets. The segment of roof slab of the spinning unit of the factory that collapsed on day 6 was 68.4 m long in the East-West direction with a downward slope of 1% from the East to the West.

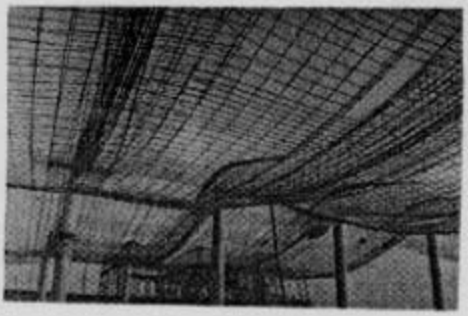
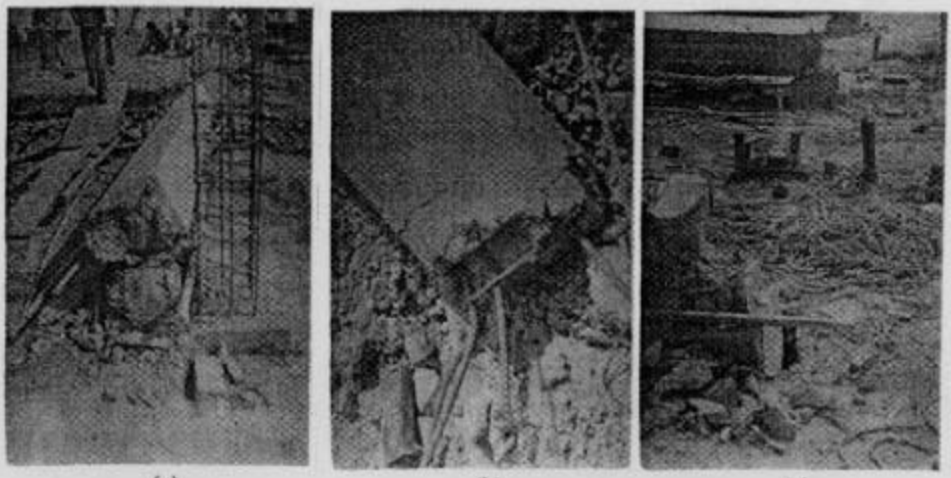


Fig. 3 Reinforcement of roof slab as well as inverted beams being held by cracked columns after the collapse of under construction roof slab in the adjoining areas



(a) (b) (c)

Fig. 4 (a) Damaged square column, (b) damaged circular column, and (c) movement of footing beneath collapsed column.

Fig. 5 Part of the collapsed roof slab showing closely spaced top and bottom bars in the slab

Accordingly, the height of the East end of the roof was 6.48 m (21 ft 3 inch) and the height of the West end of the roof was 5.79 m (19 ft) above the ground level. Inverted beams running in the East-West direction had a size of 250 mm x 600 mm to 250 mm x 900 mm. At the time of the collapse of construction work the shuttering below the on-going or recent construction work collapsed completely. The details of formwork, thus, presented in this article is based primarily on gathered from the collapsed formwork and the portion still standing. From the bamboo prop and shuttering arrangement adopted for casting the roof slab, as was made available by the owner of the factory it was evident that the drawings were incomplete and, thus, detailed information regarding the formwork could not be obtained from these drawings. In the absence of an all encompassing neat shuttering drawing with all the necessary details of prop type, prop size, bracing size, plank size, etc. and the arrangement through which all these were connected together to make a stable formwork, the adjacent formwork that was still standing in the portions not fully affected by the collapse during construction was reviewed. It was, however, clear that bamboo props were freely used in fabricating the formwork.

The "formwork" used for construction of the roof consisted of a two-stage fabrication made of bamboo props and wooden rafters and planks, supporting a concrete "form" with plain mild steel sheet base. The bamboo poles used as props of the lower stage were placed generally over pieces of wooden plank laid on the ground or directly on the ground . These bamboo poles supported a grillage consisting of wooden rafters in one direction and planks in the other. In general the overall quality of the formwork materials, specially the bamboo poles used as props, was poor. There were undersized, crooked and out of vertical poles as was evident from the existing scaffolding work near the collapsed segment. Figure 6 presents a general view of the scaffolding arrangement and quality of work.

The 3.67 m high lower stage of the overall formwork fabrication comprised of bamboo (and sometimes wooden) props and wooden rafters and planks. The planks on the top of bottom stage were in general more widely spaced. A second set of 2.13 m to 2.82 m (7 ft to 9 ft 3 inch) high bamboo props was placed on top of the bottom stage top planks. At the top of these upper props, wooden rafters were run parallel to the lower level rafters. The rafters were over lain by wooden planks. Plain M.S. sheet was then spread over the planks to form the base of the form. The upper stage props rested at the junction of a pair of planks placed side by side over the rafters at 3.67 m level, as can be seen in Fig. 6c. This made the base of the prop unstable; insertion of levelling wedges at this location might have worsened the situation. These levelling wedges were merely pieces of timber or bamboo (Figs. 6c and 6e). The props in the two stages were haphazardly arranged similar to the arrangement shown in Fig. 6a. As such the props did not form a continuous line. Even when a line of two props, where the bottom of the upper level prop could be found nearly on the top of the lower level prop, the two did not form a straight line, let alone a vertical straight line - a case typical for bamboo props. The freedom of rotation at the junction of the two props renders the resulting fabrication unreliable to support any significant load beyond its own weight. The precarious arrangement had inadequate vertical load carrying capacity and very little or no lateral stability.

The 5.79 m to 6.48 m high propping work made of crooked and slant bamboo poles, broken in the middle by the lower staging, had no lateral diagonal bracing. The so-called lateral bracing placed horizontally was not only grossly undersized (see Fig. 6d), but also they were placed, in case of bottom stage of the work, at about one-third height from the bottom instead of

approximately at half-height, as advocated in the shuttering arrangement drawing. The two-stage method was necessitated by the use of standard length bamboo poles used ordinarily in small scale low-height structures. The method could perhaps work only if the two stages were braced individually and together to form rigid table like structures. No attention was paid to buckling and stability of the poles, and rigidity of the total arrangement of formwork, props, runners, etc. The designers, erectors and supervisors of the formwork demonstrated complete lack of appreciation for the stability of high formwork. The propping arrangement used was totally unacceptable for the given work and should have been rejected before placement of concrete commenced on the roof slab, which had a downward slope of 1% in the East-West direction, as already mentioned earlier.

Faulty construction sequence

The structural system of the factory building comprised of roof slab, 4.7 m spaced inverted beams running in the East-West direction and reinforced concrete columns. Columns had been cast sometime before the casting of roof slabs. Although the reinforcement binding of the inverted beams were complete at the time of casting the slabs, none of the inverted beams were cast during the period from day 1 to day 6 when slab casting was in progress. This resulted in the casting of a vast area of slab resting on poor quality bamboo props. Casting of inverted beams after respective slab casting would have added to the overall stiffness of the slab-beam system.

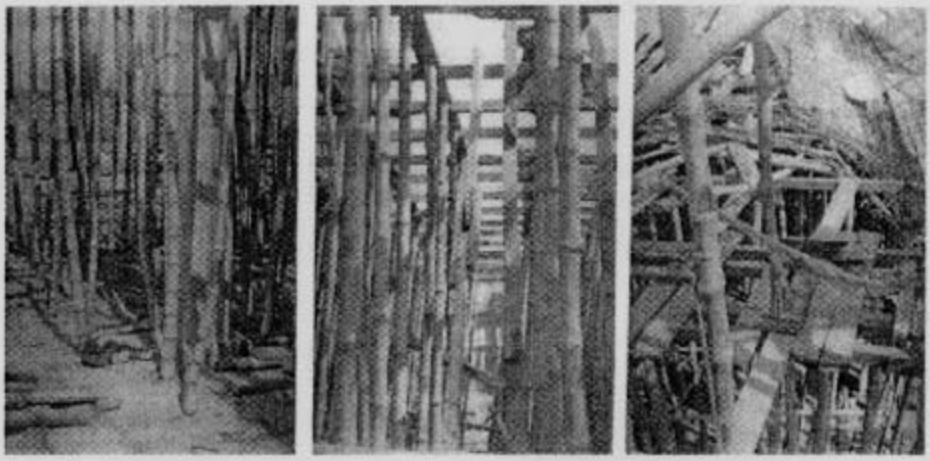
Faulty structural system

Although various structural elements such as slab with punch holes, beams, columns and footings had design deficiencies, since the failure of the under-construction roof was triggered by the collapse of the formwork at a time when the structural concrete was not supposed to be subjected to external loads, faulty design is not to be considered as a contributory factor. It is, however, worth mentioning that the roof of the factory building had only one directional (East-West) inverted beams to facilitate drainage of rain water above the roof. Absence of beams in the direction perpendicular to main beams impaired the adequacy of the structure against lateral loads.

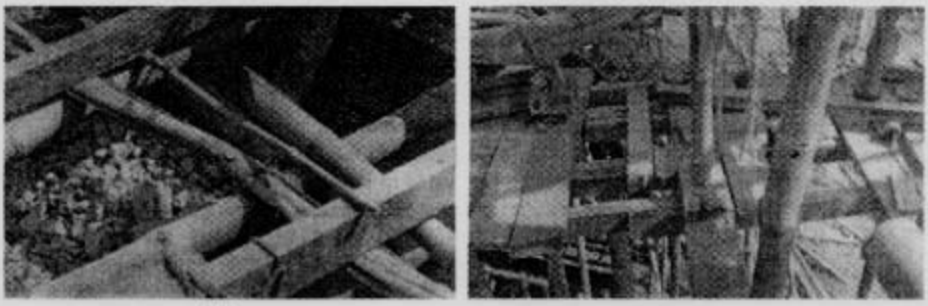
Factors triggering the collapse

The collapse of the structure was due to faulty formwork which was not capable of sustaining the forces - both vertical and lateral - during the construction work. At the time of failure, concreting operation was in progress in the area covered by row 24 and half way to row 25 (see Fig. 1). It has been reported that concreting in the middle part of this segment i.e. between row D and F was being completed and preparation for concreting towards rows A and J was in progress at the time of collapse. This left portion between D and F fully loaded at the time of collapse. Now examining the events at the time of collapse, one may only speculate, and no one will ever be certain as to which particular cause tipped the balance and caused failure of formwork and the structure it was supporting. The horizontal drag due to sloping roof and the incapability of the formwork to cater for that may be one of the factors contributing to the collapse. It is to be noted that inadequate cross bracing and horizontal bracing of the vertical members of the formwork is one of the factors most frequently involved in formwork accidents. It is possible that during the construction work in the afternoon of day 6, one or more of the poor quality bamboo props used in the formwork below the casting area were displaced by vibration caused by passing traffic or the

movement of men and equipment on the formwork, or the effect of vibrating concrete to consolidate it. Again, during casting operations, usually form watchers move under the casting area. During their movement bamboo props on the upper or lower stage could have been disturbed. Workers engaged in fixing the wedges during casting could have accidentally unsettled the prop bottoms as well. On the other hand, one or more of the already overloaded props could have gradually given in by a creep like process destroying the overall equilibrium state. Whatever may be the triggering factor, when a failure took place at one point, inadequate bracing permitted the collapse to extend to other portions of the structure and multiplied the damage and ultimately permitted a complete failure. Evidently, formwork from either side of the casting area started giving in, the inclination being towards the region E shown in Fig. 1.



(a) (b) (c)



(d) (e)

Fig. 6 (a) View of narrow as well as crooked haphazardly arranged bamboo props used in scaffolding, (b) general trend of using low quality material as props by the Contractor (bamboo props have been replaced by pieces of wooden planks put together by nails - the ensuing strength and verticality of such make-shift props is questionable), (c) upper stage bamboo props resting on the junction of a pair of planks, (d) extremely small diameter members used as bracing, (e) levelling wedges made from bamboo/timber

The faulty casting sequence, which left the casting of inverted beam unattended, also added to the overall lack of stiffness of the slab-beam system which, otherwise, could, perhaps, have arrested the chain reaction that brought down the entire structure.

MEASURES TO BE TAKEN DURING FUTURE CONSTRUCTION

Any future construction work of the factory building should be preceded by a satisfactory design of formwork. It should be well braced diagonally as well as horizontally and should be capable of resisting, in addition to vertical loads, the other effects that introduce lateral force components or introduce displacement of support members. Adequate provisions should be kept to prevent rotation of edge beam forms running in the East-West direction, where slabs frame into them on one side only. Form watchers in adequate numbers should be on the job during concreting. A system of formwork filled with wet concrete has its weight at the top and is not basically a very stable structure. Usually, good practice in designing and constructing formwork, and in handling and using it, can provide safety as well as efficiency. During casting, adequate care must be taken in an effort to ensure that at the time of concreting operation reinforcing bars are not displaced from position. Travel time for the green concrete from the mixing plant to the place of casting should be kept to a minimum. The sequence of construction as well as structural system should be worked out early in accordance with the type of design employed for the structure. The sequence must not invite instability or reduce stability at any stage during construction.

CONCLUSION

The failure of the under-construction roof of the factory building occurred due to the collapse of the formwork which was deficient in supporting its own weight together with the weight of the concrete and the construction live loads, including materials, equipment and workmen. The two-stage formwork scaffolding was inadequately designed without regard for lateral stability, poorly erected and did not employ standard materials, giving rise to a precarious support for the construction having questionable stability. The deficiencies in the construction of formwork was evident from the fact that (i) crooked bamboo poles were used as props, (ii) props could not have been truly vertical both in the lower and the upper stages, (iii) upper stage props had freedom of rotation at the base which were supported on timber and bamboo/timber wedges at the junction of two planks, (iv) there was no continuity of the props in the two stages, (v) the junction of the two stages of props at 3.67 m level had little resistance to lateral movement, (vi) no diagonal bracing was used to stabilize the formwork fabrication and the slender props were free to buckle and get displaced, and (vii) that the so-called lateral bracing provided horizontally was inadequate to serve the purpose. The faulty construction sequence also contributed towards the collapse.

REFERENCE

1. DEPARTMENT OF CIVIL ENGINEERING, "Report on the Collapse of an Under Construction Factory Building", BRTC, BUET, Dhaka, May, 1996.