

## BUILDING STRUCTURE FAILURES CAUSED BY DEFECTS IN WORKMANSHIP

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### Abstract:

The article presents the characteristics of collapses of three building structures which occurred as a result of defects in workmanship, including the Hyatt Regency Hotel building in Kansas City, a building in Shanghai and the roof over a part of the grandstand at the stadium of FC Twente in Enschede. These events had a global impact. The paper describes also the construction of and the repair of damage to the elevated reinforced concrete tank for storing liquids.

### Keywords:

failure, building structure, defect in workmanship, repair, safety

## INTRODUCTION

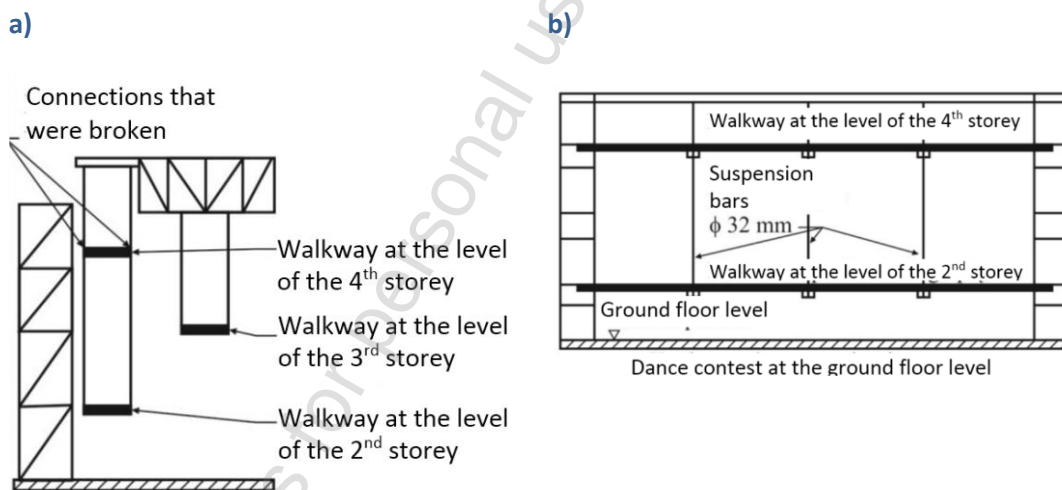
A failure caused by poor workmanship can occur during the construction process, in which case it is defined as a building collapse, or it can pose a threat to the building's structural system to the extent that renders it unfit for the intended purpose [2].

The paper describes the failures caused by defects in workmanship, using the following as examples 1) the Hyatt Regency Hotel building in Kansas City, the U.S., 2) the roof over the grandstand at the stadium of FC Twente in Enschede, the Netherlands, 3) a residential building in Shanghai, China, and 4) a tank for liquids in Głogów. The reasons for these structural failures were quite simple. In the first example the mistake

consisted in doubling the load of the steel bar connection, which resulted from an ill-advised change/modification of the suspension of the walkway, i.e. replacing one bar with two, introduced by the contractor in an important design detail without any written approval from the structural designer. The second example also concerns a steel structure, composed of relatively slender elements susceptible to the loss of stability, which actually occurred, because of the lack of bracing elements combined with the simultaneous premature installation of a video camera and the application of other service loads. This mistake resulted from the lack of indispensable coordination and inspection to ensure the safety of the structure [1]. The collapse of the building in Shanghai and the damage to the tank in Głogów also occurred because of simple errors, attributable to contractors' ignorance rather than to design shortcomings [4], [11].

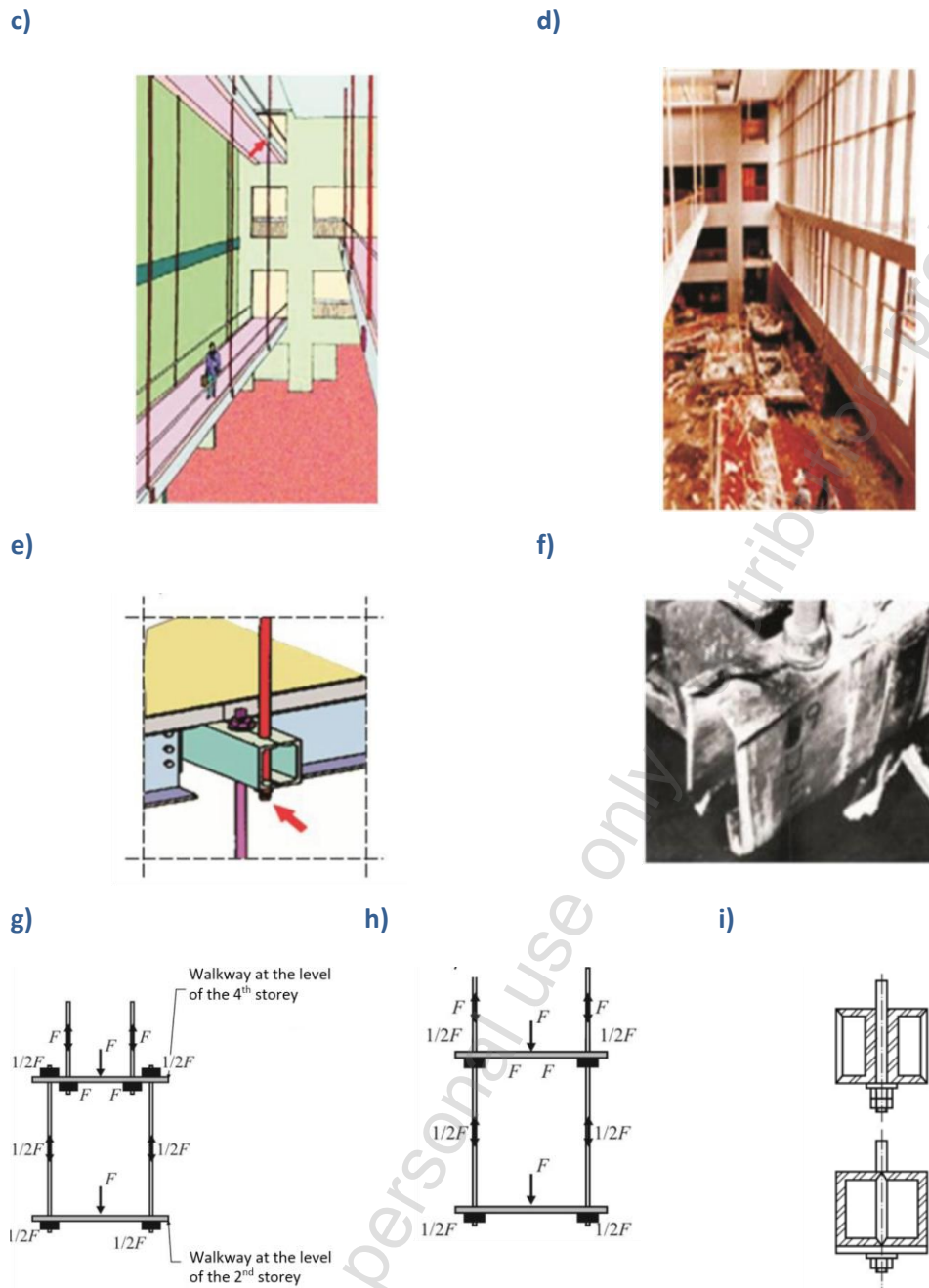
### 1. COLLAPSE OF TWO SUSPENDED WALKWAYS IN THE HYATT REGENCY HOTEL IN KANSAS CITY, THE U.S., IN 1981 [8]

In 1981, in the newly opened Hyatt Regency Hotel in Kansas City two suspended walkways collapsed (Figure 1a) b) c)). The walkways connected the floors on the second and fourth storeys in the hotel atrium and they fell down on the participants of a dance contest organised by a local radio station, killing 114 and wounding 186 people. It was one of the most tragic building disasters (Figure 1d) that occurred in the U.S. The main reason for the collapse of the walkways at the fourth and second storeys was a change in the way of suspending them, introduced by a contractor, replacing the design solution using one bar (Figure 1h) with a two bar system. Thus, in the modified version (Figure 1g), the force applied to the nuts supporting the walkway at the fourth floor was doubled, as a result of which they were subjected to the load  $F$ , instead of  $\frac{1}{2} F$ , specified in the design version (Figure 1h).



**Fig.1.** Collapse of two suspended walkways in the Hyatt Regency Hotel in Kansas City, the U.S., in 1981 [7]: a) short section of the atrium with the truss system to which the bars were attached [6], b) long section of the atrium with the walkways on the fourth and second storeys

Source: [5]



**Fig. 1.** c) view of the atrium before the walkways collapsed, indicating the nut on the upper walkway (the fourth storey), which was broken, d) view of the atrium after the walkways at the second and fourth storeys collapsed, e) view of the attachment of the bars in the box-section rib, consisting of two joined channel bars, in the as-built version, indicating the nut to which the double force was applied, as compared to the value assumed in the design, f) view of the damaged rib after the bar was pulled out, g) suspension detail in the as-built version [13], h) connection detail in the design version [13], i) improvements proposed for the connection of wire ropes and box-sections to increase their load-bearing capacity [3]

Source: Authors' archive

## 2. COLLAPSE OF A PART OF THE ROOF AT THE STADIUM OF FC TWENTE IN ENSCHEDE, THE NETHERLANDS

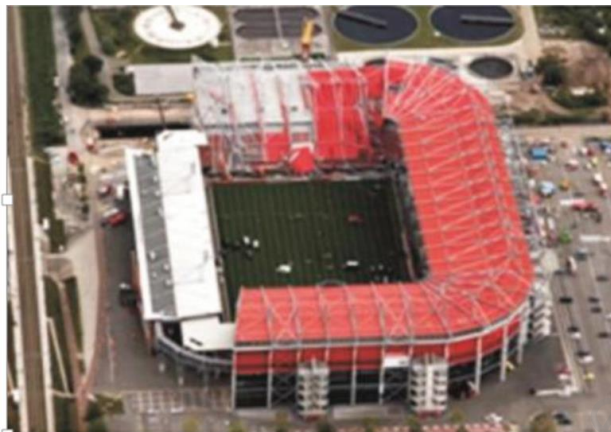
Roof over a part of the grandstand at the stadium of FC Twente in Enschede (Fig. 2) collapsed at 7:30 a.m. on 8 July 2011.

At the time no match was played at the stadium and the rebuilding works were carried out at its grandstand.

Report [9] (see: [12]) prepared by the Dutch Safety Board concludes that the collapse of the roof occurred as a result of the lack of horizontal bracings at the back of the structure.

The investigation revealed that the main contractor did not check the sequence and method to be followed while carrying out the roof.

a)



b)



c)

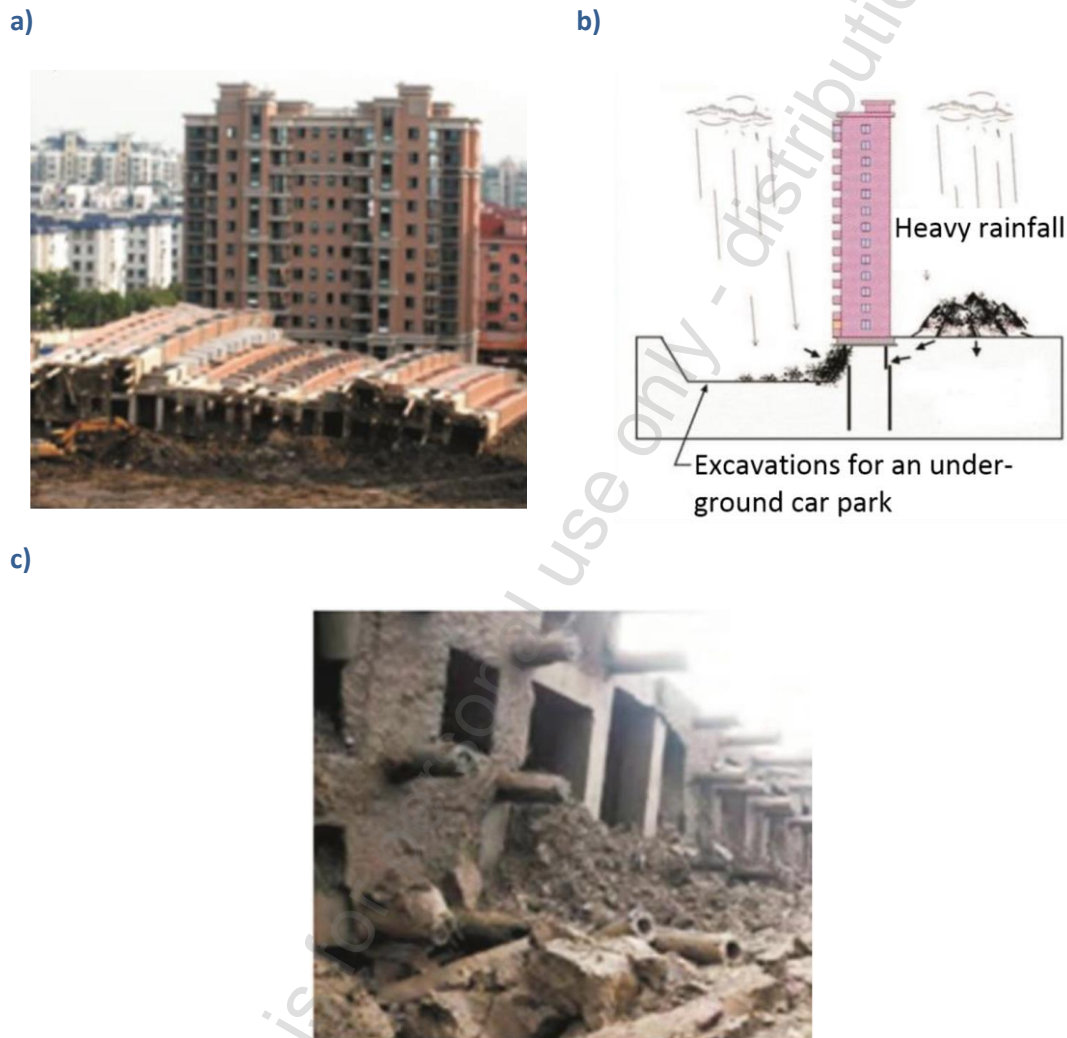


**Fig. 2.** Collapse of a part of the roof over the stadium of FC Twente: a) general view of the stadium, b) view of the roof of the stadium of FC Twente after its collapse (photo: AFP), c) short section of the roof with a suspended structure over the grandstand at the stadium.

*Source: Authors' archive*

### 3. COLLAPSE OF A BUILDING IN SHANGHAI, CHINA, 2009

In 2009, a 12-storey building, yet uninhabited, in Shanghai, China (Fig. 3a), collapsed as a result of employing inappropriate workmanship methods. These included: a) carrying out excavations to the depth of 4.6 m on the south side of the building, b) storing the excavated soil on the opposite, north, side of the building, to the height of 10 m. As a result of the above, the building resting on the piled foundation was subjected to unequal pressure coming from the south and from the north. The value of unbalanced horizontal pressure totalled about 3,000 ton. The exerted pressure exceeded the value that could be safely transferred by the piles without breaking them. Thus, the building fell over to the south. It was observed that a heavy rainfall, continuing for several days, contributed negatively to the accident. The described situation is presented in Figure 3b.



**Fig. 3.** Collapse of a 12-storey building in Shanghai, China [11], [14]: a) view after the building collapsed [10], b) probable mechanism responsible for the collapse: 1) heavy rainfall, 2) different values of horizontal pressure exerted by the ground, 3) the building shifted and a shear failure of the reinforced concrete piles occurred, c) view of a section of the piles at the bottom of the building

*Source: Authors' archive*

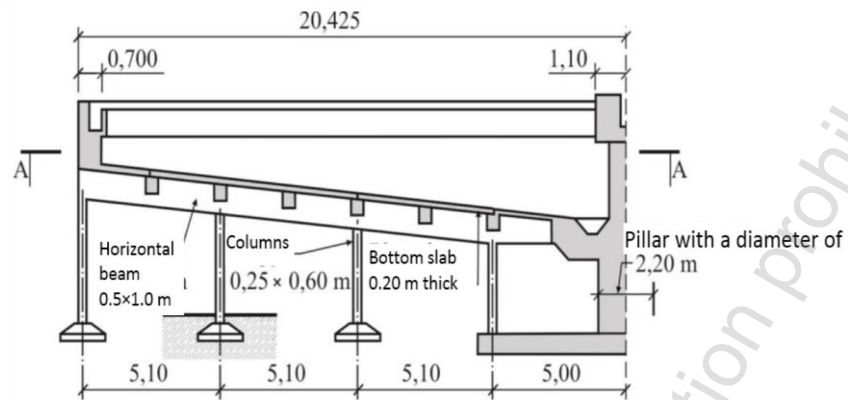
#### 4. DAMAGE TO THE STRUCTURE OF THE ELEVATED DORR'S CLARIFIER, WITH A CAPACITY OF 3,000 m<sup>3</sup>

After 23 years of operation in the elevated clarifier made of reinforced concrete (circular plan see: Figure 4a, b, c), intended for process liquids (Figure 4d), cracks were detected in its supporting structure (Figure 4e, f) as well as seepages and damp patches (bloom) visible from outside (Figure h) [4]. The supporting structure of the clarifier is formed by 24 radially arranged frames, composed of four-span horizontal beams, having the dimensions of 600 × 1,000 mm, supported by the central pillar, with a diameter of 2.20 m, and three columns, having the dimensions of 250 × 600 mm. In the direction of the circumference beams are placed, with a cross-section of 500 × 500 mm and spaced every 2.55 m. The arrangement of horizontal beams and beams forms a grate on which the bottom slab of the clarifier, 200 mm thick, rests. In the direction of the circumference, there are three expansion joints in the bottom slab, owing to which its three concentric parts can be distinguished, namely: a) circular central slab, with a diameter of 10.00 m, monolithically connected to the central pillar, limited by the circumferential beam from the outside, b) external ring slab, with the slab strip 2.55 m wide, monolithically connected with the vertical wall of the clarifier, 2.53 m high and 700 mm thick, and c) two strips with the width equal to the spacing of the columns, i.e. 5.10 m, separated with expansion joints. Both these strips are also radially separated by expansion joints in the axis, spaced every third horizontal beam. Expansion joints are filled with a 19 mm thick strip of soft fibreboard. At the top, the pointing of expansion joints was made with monolith. To make it possible for the bottom slab to move (except for the circular central part) in relation to the supporting frame structure, a separator made of building paper was placed between them, but it did not serve its purpose.

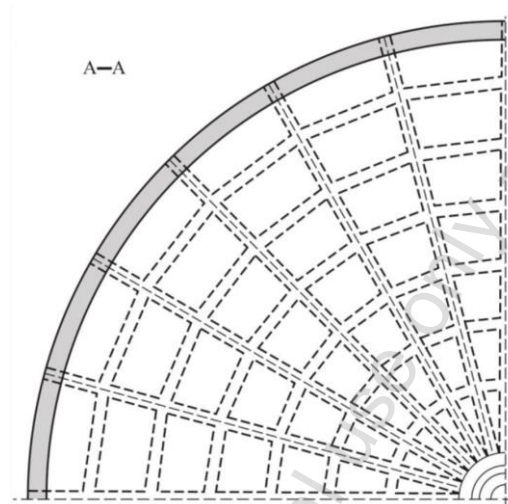
The damage presented in the photos was caused by both defects in workmanship (incorrect reinforcement of frame corners) and design errors (insufficient coating of reinforcement bars in the structural members of the clarifier). The first mistake is explained in Figure 4j, presenting the completed reinforcement of the frame corner together with reinforcement bars. The incorrect placement of reinforcement in the column at the height of the horizontal beam (out of plumb instead of being parallel to the outer side of the column) and the lack of reinforcement in the upper fibres of the corner, combined with the simultaneous action of tensile forces transferred through friction caused by the movement of the liquid heated by  $\Delta T$  60°C (temperature of the sludge) along the upper surface of the horizontal beam, with the simultaneous shrinkage occurring in the horizontal beams  $\Delta T = -20^\circ\text{C}$ , caused the cracking of the corners (Figure 4e).

The insufficient coating of reinforcement of the structural members, combined with the concurrent action of aggressive liquids (sulphuric acid with a pH value of 2.0-3.0 and chlorides in the amount of at least 1,000 mg/dm<sup>3</sup>) contributed to the degradation of concrete at the bottom (Figure 4h). Such degradation occurred also on the external surfaces of the columns, due to the presence of harmful gases at the time of precipitation events (Figure 4i).

a)



b)



c)

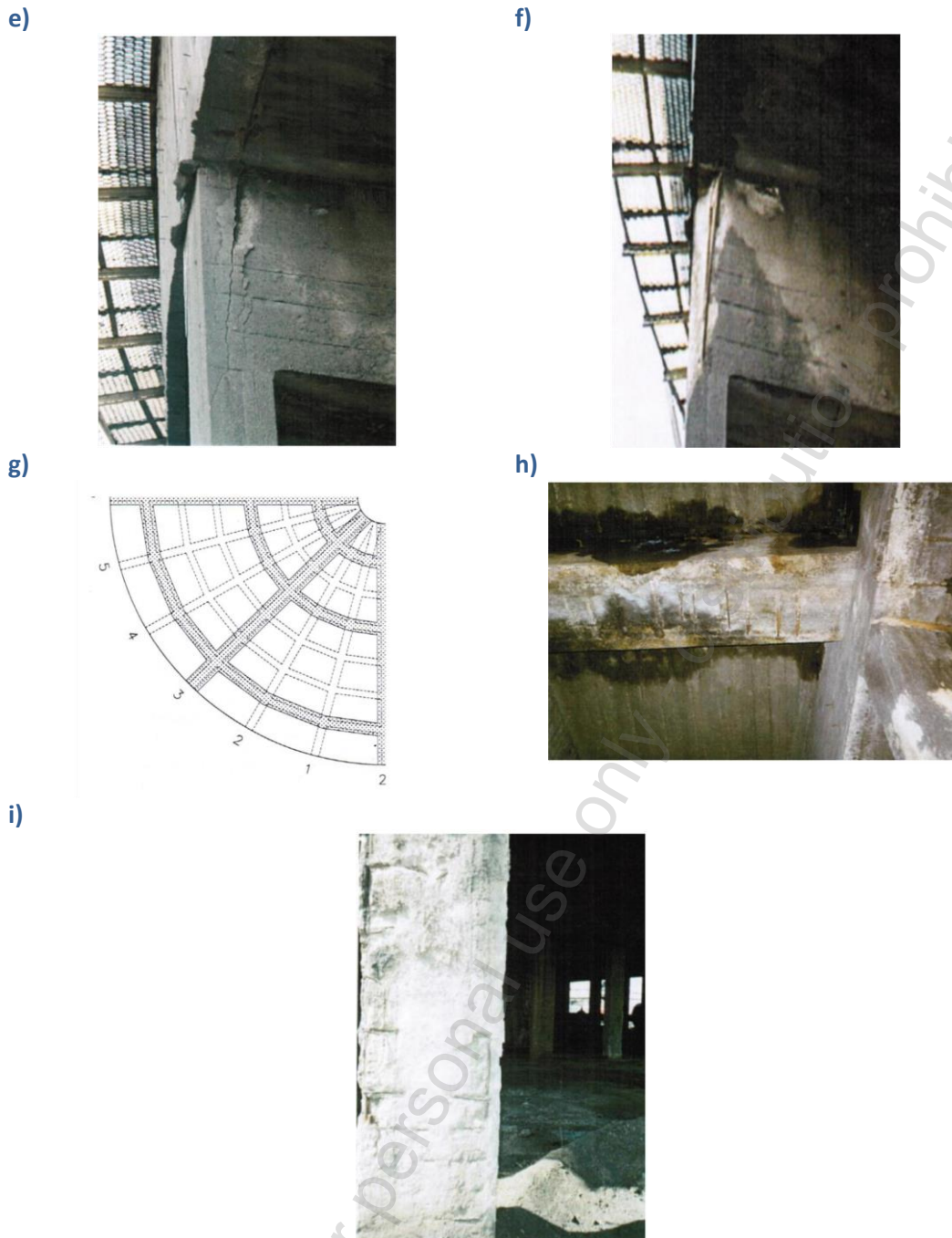


d)



**Fig. 4.** Structural damage to the elevated Dorr's clarifier at Huta Miedzi (copper smelting plant) [4]: a) vertical cross-section of the clarifier, b) plan of the clarifier, c) general view of the clarifier, d) view of the clarifier filled with sludge

Source: Authors' archive



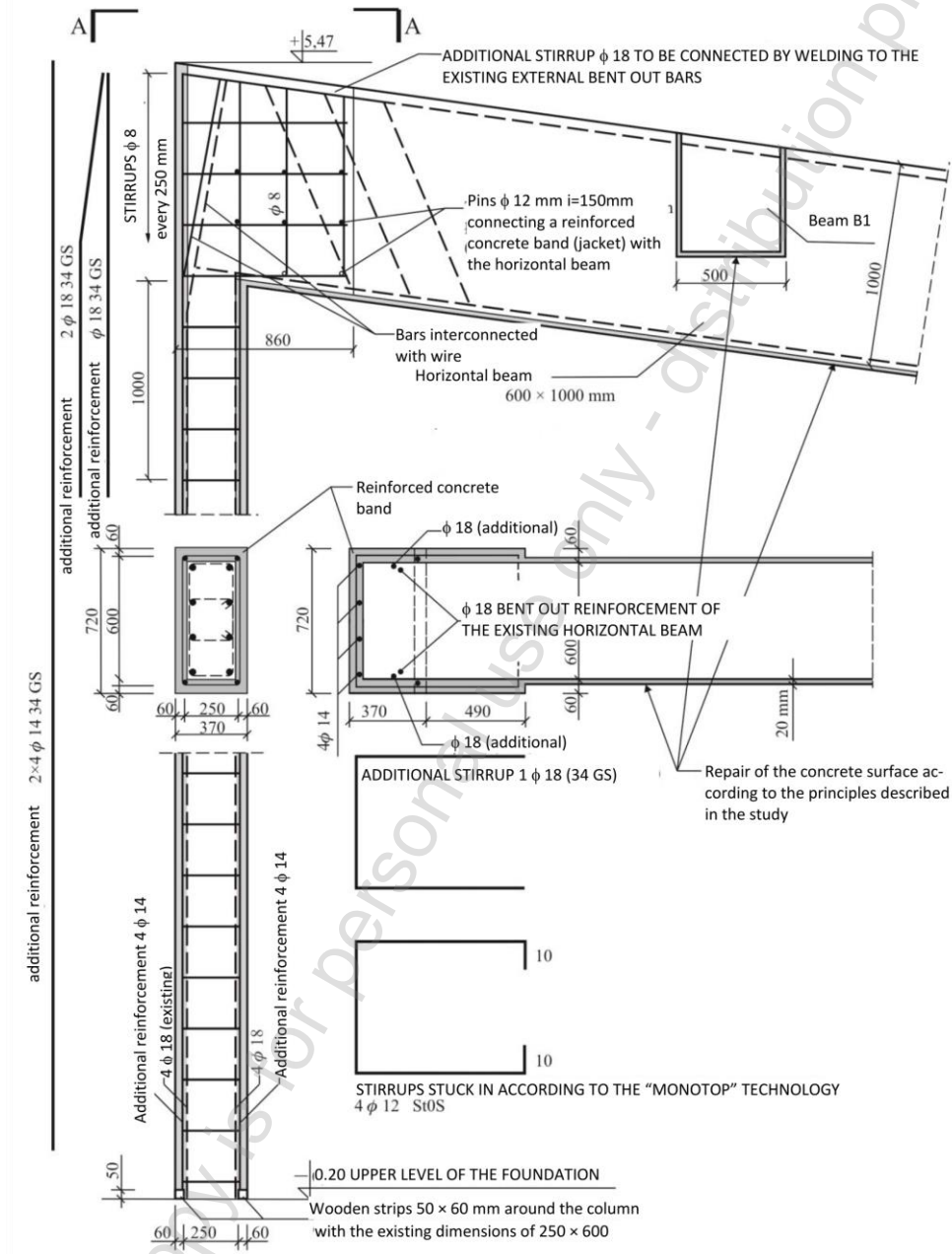
**Fig. 4.** e) cracked corner of the frame with lumps of concrete falling off, due to thermal deformations of the reinforced concrete structure of the clarifier, f) view of the corner – as in the photo, e) after the removal of lumps of concrete falling off, g) indication of places with seepages and bloom along the leaking expansion joints, h) underside of the bottom slab of the clarifier and the supporting structure with visible seepages and bloom and exposed corroded reinforcement bars, i) photo of the column illustrating its damage, including defects, cracks in the concrete around the bar and corroded reinforcement bars

*Source: Authors' archive*



To ensure the failure-free operation of the Dorr's clarifier it was decided to [4]:

- strengthen the external columns and frame corners by placing reinforced concrete bands (Figure 4j), after preparatory and renovation works have been completed;
- repair the whole outside surface of the clarifier;
- repair the expansion joints and the inside surface of the clarifier, including the application of a chemically-resistant coating.



**Fig. 4. j)** strengthening of the frame corner and the column with a reinforced concrete band

Source: Authors' archive

## CONCLUSION

Taking account of the presented data and the reports drawn up by the investigation teams examining the reasons for failures, it can be concluded that the above building failures could have been easily avoided. The buildings met the requirements specified in their structural designs, however, either the process of design verification was inaccurate or the procedures adopted for construction projects were neglected. By extending the knowledge of reasons for failures and behaviours of buildings under construction the structural safety can be enhanced and, thus, failures caused by defects in workmanship can be reduced to the minimum.

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## BIOGRAPHICAL NOTES

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Forces and the Civil Defence to overcome the consequences of crisis situations and to restore the damaged infrastructure; theory and practice of crisis management, mainly at the local government level; security of transport in crisis situations; civilian planning in the security system.

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