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Performance Deficiency of Department Store – Case Study

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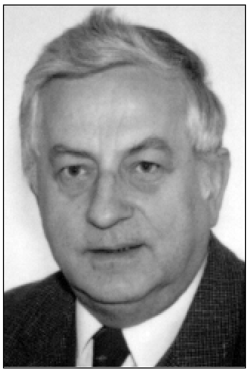

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Summary

Load bearing structure of a recently built department store in Prague consists of a flat (double ribbed) reinforced concrete slabs supported directly on columns located within span distances 12 x 12 m. Slabs above the first and second storey cantilever out by 3 m beyond the edge columns. After few years in service serious performance insufficiencies of cladding, interior partitions, and other secondary elements had been observed. Due to public perception of the observed faults the second storey was closed and the whole building has been reconstructed. Detailed analysis has shown that serviceability failure of the second storey was primarily caused by lack of consideration in design of deflection due permanent load and shrinkage. Presented theoretical model for uncertainty and vagueness in perceiving observed defects explains well disturbing discrepancies in both public perception and expert assessment of structural condition.

Keywords: Department store, safety, serviceability, risk, public perception

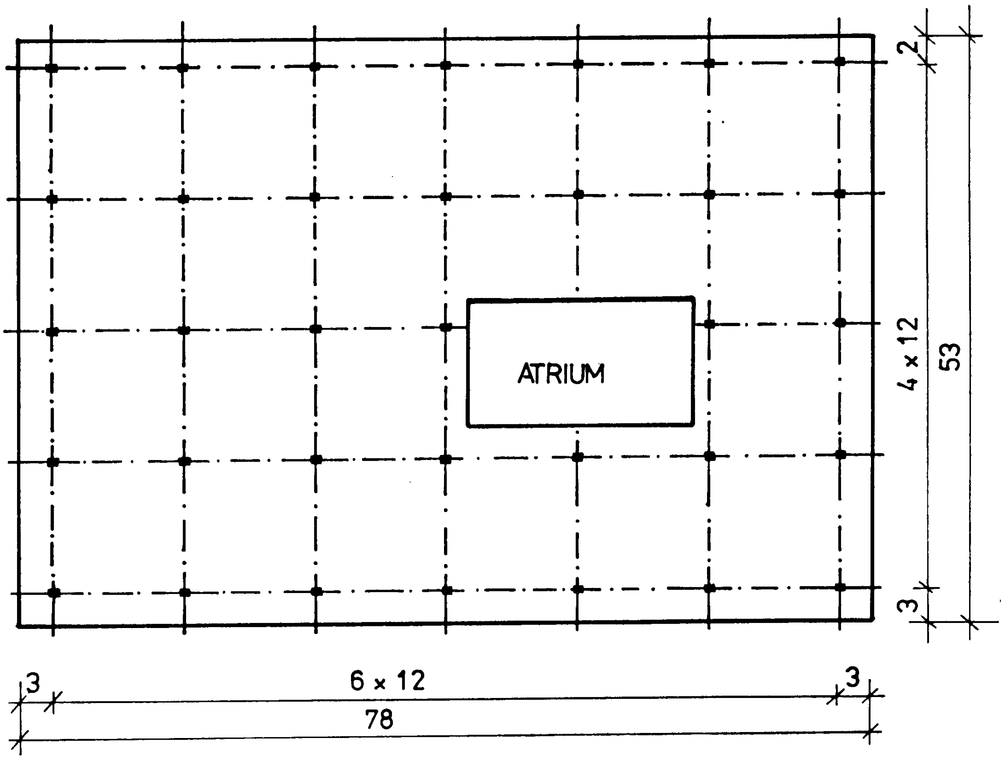
1. Introduction

Recently built department store in a new suburban town is one of the most important social facilities of the large urban locality in Prague. Public building of this type should naturally comply with all functional requirements, including serviceability conditions, with relevant high level of reliability. Unfortunately, shortly after its completion, several structural defects (cracks, deflections) have been observed.

Incidentally at the same time another department store of the same user collapsed. This was perhaps partly the reason why all the performance insufficiencies of the new building had been watchfully recorded and publicly reported, although the collapsed department store was a steel structure and its failure occurred due to well-recognised reasons. Unfavourable engineering climate (psychological aspects) seems to play a significant role in the subsequent assessment of structural damage. Observed defects were often exaggerated and interpreted as structural condition indicating insufficient safety against collapse, not just serviceability defects. Consequently, after less than 10 years in service, the second storey of the two floors building was closed and damaged non-bearing components were reconstructed.

2. Load Bearing Structure

Plan view of the building of the gross area 78 × 53 m is schematically indicated in *Fig. 1*. Load-bearing structure consists of reinforced concrete double ribbed slabs of the total thickness 0,45 m (see *Fig. 2*) supported directly on columns of the cross section 0,5 × 0,5 m or 0,7 × 0,7 m located within span distances 12 × 12 m (see also *Fig. 3*). The slabs are provided by hidden heads of the plan view dimensions 1,65 × 1,65 m (at the edge columns) and 3,35 × 3,35 m (at the interior columns), where the coffer ceiling is replaced by solid slab. In the remaining part of the slab, the ribs of the cross section 0,18 × 0,38 m support thin plate (of the thickness 0,07 m and interior spans



0,8 × 0,8 m). Equivalent thickness of the solid slab having the same rigidity would be 0,34 m only, which indicates that stiffness of the slab is very low. Moreover, slabs above the first and second storey cantilever out beyond edge columns by 3 m.

Fig. 1 Plan view of the department store

Fig. 2 Section view of the department store

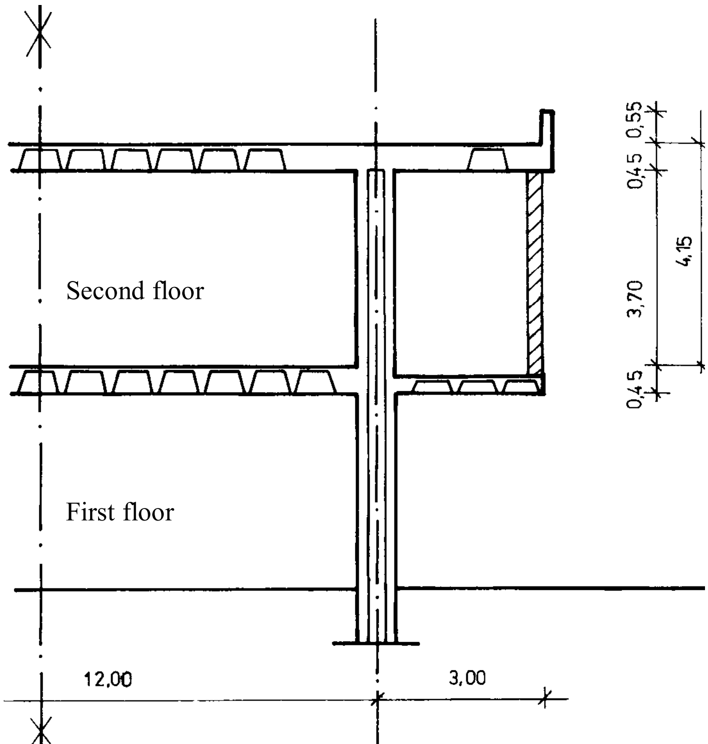


Fig. 3 Internal view of the department store

Design loads of the slab above the first floor considered in the original analysis consist of permanent part 7,0 kN/m^2 and temporary part 4,0 kN/m^2 , corresponding values for the second storey slab are 7,2 kN/m^2 and 1,5 kN/m^2. However, actual permanent load of the slab above the second floor is due to actual roof and ceiling greater and could be as high as 10 kN/m^2. Nevertheless, the ultimate strength of the slab is, according to the revised Czech standards [1,2] sufficient, and therefore no strengthening of the load bearing structure was needed [3]. The whole reconstruction then concerns merely the damaged non-bearing structures.

3. Non-bearing Elements

Non-bearing elements of the second storey, which were affected by deformations of bearing structures consist of façade cladding, interior partition walls and interior built-in components like glass walls, and shelf stands. Cladding of the building consists of large glass windows, brick walls and window pillars, located within regular distances of 2,4 m. The window pillars, reinforced by steel ties anchored into floor and ceiling, were built in the bearing slabs without any expansion joints. Similarly all interior masonry partition walls, reinforced by rolled steel elements of I- and U-section were constructed without any separation from roof slab. Expansion joints were not used in any interior built-in components. All of these non-bearing structures were evidently designed without desirable consideration of different deflection of both floor and ceiling slabs due to their different stiffness and loading.

4. Performance Deficiencies

After few years in service serious performance problems concerning cladding as well as interior non-bearing structures have been observed and analysed [3,4]. The most alarming were perhaps defects appearing in non-bearing structures: cracks of partition walls (see *Fig. 4* and *Fig. 5*) deformed doorframes and buckled shelf stand, which were especially apparent and impressive. Also cladding elements were damaged. Tensile cracks of window pillars were particularly noticeable near to the exterior corners of the building (see *Fig. 6* and *Fig. 7*).

Fig. 4 Partition wall

Fig. 5 Partition wall

Fig. 6 Façade corner

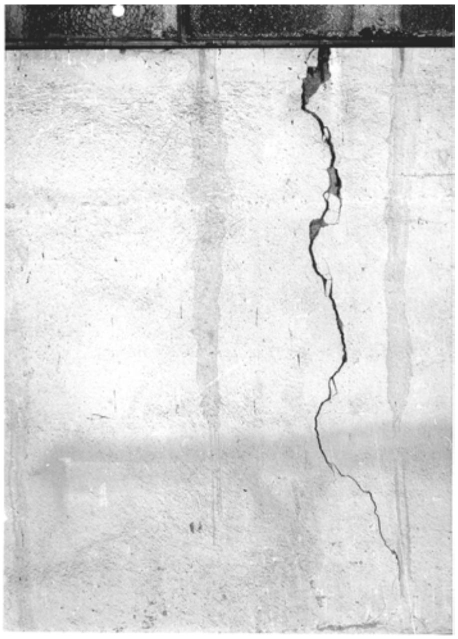


Fig. 7 Façade wall

There were also sporadic shear cracks in slab ribs close to hidden column heads found, however, mostly near to construction joints only. These cracks, which were less important for the overall damage assessment of the building, were the only detected defects of the load bearing structure. All other performance insufficiencies concern merely non-bearing structures.

5. Defects Causes

All of the defects of non-bearing structures in the second storey are caused by different deflection of the floor slab (above the first storey) from deflection of the roof slab, primarily due to permanent load and shrinkage. As mentioned above the permanent load of the more flexible roof is by 3 kN/m^2 greater than that of slightly less flexible floor slab. This could lead to considerable differences in midspan deflection (shortening up to 30 mm) as well as cantilever deflection (extension up to 5 mm, at exterior corner up to 10 mm). Also shrinkage may lead to similar mutual differences in slab deflections; midspan shortening and cantilever extension may reach 5 mm (extension at exterior corners may be 10 mm). Deformations due to temporary load and temperature are less important and may cause the maximum midspan extension 6 mm and shortening 1 mm, cantilever extension or shortening less than 1 mm. Observed deformation effects well correlate with theoretical results. Unfortunately no calculation of structural deformations had been made in original design documentation. This was partly due to inadequate provisions provided by contemporary standards.

Another construction fault mentioned above concerns permanent load of the roof slab. Due to actual own weight of the ceiling and roof (slope concrete layers) the permanent load of the slab is by 30 % greater than that assumed in design calculation. However this discrepancy is also due to negligence of some load components in design calculation. Also actual permanent load of the slab above the first storey may be slightly greater than that considered in design. Even though the deformation effects would be considerably lower if the actual load equals the assumed load, many of serviceability defects would anyhow appear. This concerns above all cracks in cladding elements particularly at the exterior corners of two-way cantilevered slabs.

It follows that most of the observed defects were primarily due to lack of consideration in design of deflection and due to inaccurate determination of design load. Construction errors, however, considerably enhanced unfavourable deformation effects.

6. Repair

Although there were almost no defects apparent on load bearing structural components (except sporadic shear cracks in ribs), it has been decided to close the second storey and to reconstruct most damaged interior partitions and other non-bearing structural components as well as cladding components. Interior partitions including reinforcing steel elements have been separated from the ceiling and new expansion joints have been covered by panel strip. New ties located near window pillars had mutually tied up cantilevered slabs. These measures have been proposed by the designer, even though additionally made analysis show that expected deformations due to temporary load and temperature (as mentioned above) are limited, and in some cases could be admitted without any modification of non-bearing structures.

7. Public perception

Public perception (recently discussed in [5]) played an important role in the assessment and final decision concerning the building. New department store became soon the building closely watched by a large population of users and local authorities. Incidentally, at the same time another department store suffered from construction faults and this was partly the reason why all the performance deficiencies have been carefully recorded (similar experience is notified in [5,6]). This unfavourable engineering climate seems to enhance intensity of public perception. Observed defects were often exaggerated and regarded to as indicators of insufficient structural safety. Widespread public perception of defects and discrepancies in experts assessments were reported in newspapers and finally resulted in a strong communal pressure on strengthening of the building.

8. Theoretical model for public perception

Evaluation of public as well as experts assessments has indicated that there is no distinct point in any performance indicator x (e.g. deflection, crack width) that would separate acceptable and unacceptable structures. Rather there seemed to be a transition region <a, b> in which the structure gradually becomes unserviceable and the degree of caused damage $\nu(x)$ increases [4,7]. A conceivable model for $\nu(x)$ is indicated in *Fig.8*. Obviously, at any damage level $\nu(x)$ there may be a perception scatter expressed by distribution function $\Phi_P(x,\mu_P,\sigma_P)$, for which lognormal distribution having the mean $\mu_P = x$ and standard deviation $\sigma_P = s \times a$ is accepted here. Taking into account all levels $\nu(x)$, the cumulative damage $\Phi_D(x)$ is [4,7]

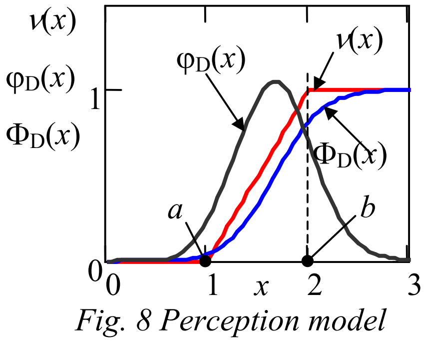


Fig. 8 Perception model

$$\Phi_D(x) = K\int_a^b \nu(\xi)\, \Phi_P(x,\xi,\sigma_P)\mathrm{d}\xi \qquad (1)$$

where K is the normalising factor. Cumulative damage $\Phi_D(x)$ and corresponding density function $\varphi_D(x)$, shown in *Fig.8* for $a = 1$, $b = 2$ and $s = 0{,}3$, can be considered as generalised probabilistic models (involving economic aspects) [4,7]. Considering appropriate load effect E (e.g. deflection, crack width) expected perception level π can be defined as

$$\pi = \int_{-\infty}^{+\infty} \varphi_E(x)\, \Phi_D(x)\, \mathrm{d}x \qquad (2)$$

Here $\varphi_E(x)$ is the probability density function of E; gamma distribution having the mean equal to the lower limit of the transition region a and coefficient of variation 0.2 is assumed in the example shown in *Fig. 9*, where expected perception level π is indicated as a function of the ratio $(b\text{-}a)/a$ for selected σ_P. It follows from *Fig.9* that the expected perception level π is strongly dependent on the width of transition region b-a, which may further depend on sensitivity or experience of an observer. This finding explains observed differences in public perception and discrepancy in expert assessment.

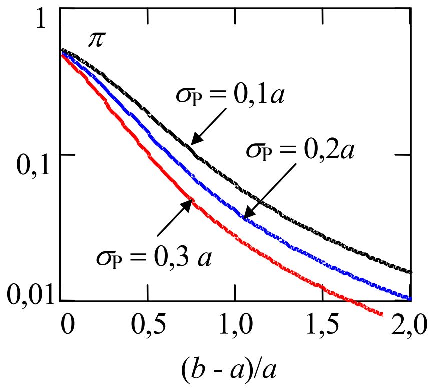


Fig. 9 Expected perception level π

9. Conclusions

1. Serviceability failure of the department store was primarily caused by lack of consideration in design of deflection due to permanent load, shrinkage, temporary load and thermal actions. Construction faults (additional permanent load and imperfect anchoring of cantilever ties) had increased unfavourable deformations.

2. Current engineering climate (psychological aspects) seems to play an important role in the public perception of performance deficiencies, subsequent structural assessment and decision made by the constructor and public authorities.

3. Disturbing variance in public perception and in expert assessment of observed defects may be well explained using proposed theoretical model for public perception.

10. References

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