EFFECT OF STRUCTURAL DEFORMATIONS ON ADJACENT BRITTLE COVERINGS

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1. Introduction

Coverings directly fastened to, or interacting with, the structure are often incapable to support structural deformations, they instead break, rupture, detach, or suffer another damage. Such damages are known to be of a wide range, often published in special literature [1].

Alongside with the abrupt constructional changes in the past decades, also covering damages have multiplied, attributable to the coincidence of several factors, such as:

- several, actually applied structures undergo greater deformations than do conventional structures (application of materials of higher strength, reduction of safety factors etc.);
- great many covering types with different material characteristics, raising increased requirements for subbases, have been introduced, etc.

Covering damages can ever less be prevented by conventional means, by strictly specifying the construction process in building codes. Failure being attributed to deformations, mainly those of the supporting structure, there are several suggestions to limit structural deformations in order to prevent similar covering damages [2], [3]. Besides, advent of a high number of coverings of different materials and types urges to develop a design method involving material characteristics.

No reliable information concerning solution of the problem has been available either in Hungarian or in foreign literature, motivating to examine deformability of coverings directly fastened to structural members, primarily brittle ones, the most sensitive to deformations, in the frames of a COMECON target program.

2. Experimental

In 1979/80, a test series had been performed in the Laboratory of the Department of Strength of Materials and Structures to determine ultimate deformation values for the most common covering types and deformation constraints, and to obtain a deeper knowledge of the covering behaviour by measuring deformations and displacements.

In conformity with building practice, the structure has been modelled by compressed concrete and flexural reinforced concrete members (UF-MV), 10 + 3 specimens in all.

From the aspect of deformations, covering tiles of big surface, high modulus of elasticity are the poorer, of them the following two were tested:

Tile MSz 53/1—77 150×150×5.5 mm,

Stoneware tile MSz 3553—78 150×150×7.5 mm.

A point in selecting was the rather different rigidities, while identical sizes and bonding technologies provided for comparability.

Bonding was made either with an admixed lime mortar Ha 10, 15 mm thick, complying with the former Hungarian Building Process Code [4], or with an up-to-date single-component, silicate based tile adhesive (SZILETON-R).

From among possible deformations of the supporting structure, the following were examined:

a) contraction without bending (e.g. walls):

b) contraction with concave bending (e.g. floor covering at midspan):

c) strain concentrated in cracks with convex bending (e.g. ceiling finishes, floor coverings over a support).

The effect of repeated loads on the connection has been simulated by 70 repetitions of the deformation corresponding to the load at the serviceability limit state of the r.c. slab.

Applying edge tiles stuck practically without displacement (by a resin mortar), the case where, in addition to bonding, also edge clamping forces the covering to interaction, has been specially considered (phenomenon of arching).

A typical example of test layout, with measurement spots and kinds, is seen in Fig. 1.

3. Stress pattern in the covering

In the tested cases, the covering and its subbase are dynamically interacting. For a possibility of surface force transfer, interfacial shear parallel with the surfaces arises between the two layers. The connection may be:

1. by adhesion;
2. by sliding-friction hence plastic;
3. viscous (Fig. 2).

Experimental deformometry showed the tested coverings to exhibit, after a short elastic range, the stress pattern in scheme 2. The plastic friction character of the connection is no wonder, a similar behaviour was found for the connection between concrete layers in interaction [5], or for reinforcement anchorage.

No plastic redistribution of normal adhesive forces can be accounted for, they exhibit an elastic behaviour.

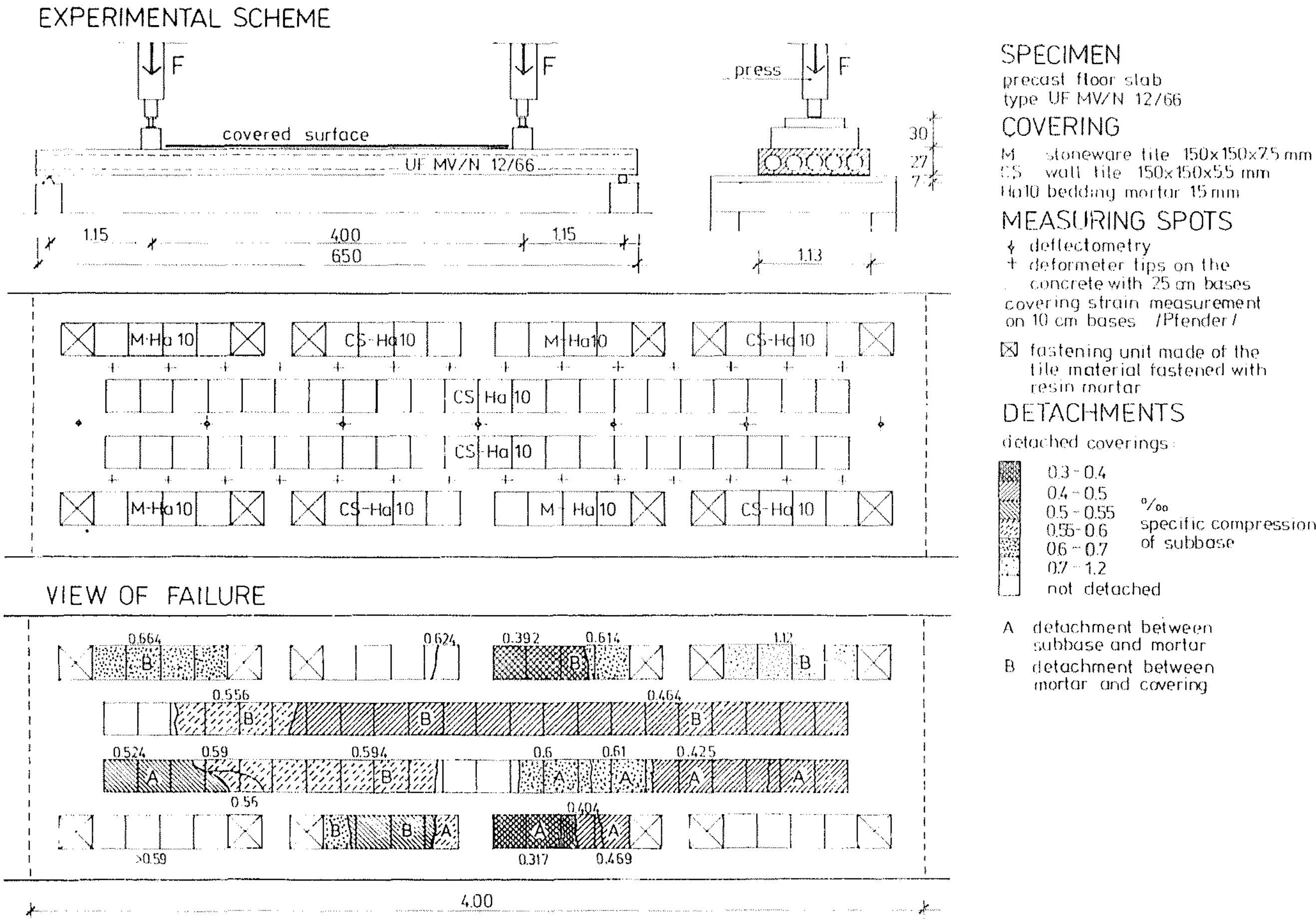

Fig. 1. **Testing coverings on a flexural unit**

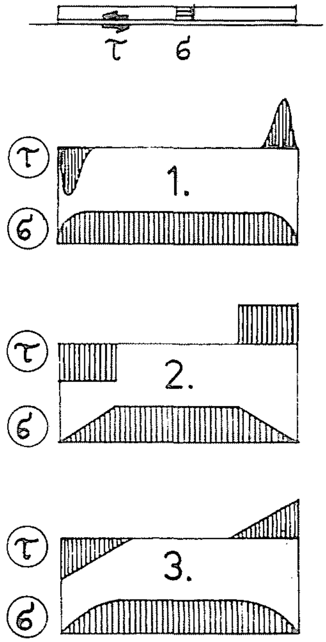

Fig. 2. Types of the adhesive-shear connection [6]

The nearly identical deformations at failure obtained on compressed and flexural specimens showed — opposite to hypotheses in the special literature — the imposed strain (unit deformation) rather than the bending to be decisive for covering damage. Namely for curvatures common in our structures ($1/\varrho > > 100$ m) the tested thin coverings follow the curvature arching. (Of course, increasing rigidity of the covering, or poor adhesion of the bond may allow the curvature to elicit detachment normally to the surface.) Curvature is only decisive for the specific strain values in the covering plane, and its limitation from this aspect may be effective for flexural beams.

4. Covering failure types and relevant ultimate deformations

4.1 Covering forced to contraction ("compressed"). with edges freely displaced relative to the subbase, or both ends clamped behave differently.

A free-edge covering fails in shear along the free edge. The failure is due to edge displacement (Δl_p) relative to the subbase, exceeding the value to be supported by the bond, typical of the connection (Table 1). If adhesive-shear forces can provide for perfect interaction between subbase and coat, displacement of the free edge is:

$$\Delta l_p = \frac{E_a^2 \cdot E_f \cdot t_f}{2\tau_R}$$

where

E_a — specific strain of subbase after coating;
E_f — average modulus of elasticity of the covering (with joints);
t_f — covering thickness;
τ_R — plastic adhesive-shear strength of the bond.

This relationship points out to be the most efficient way to prevent covering damages — beyond reducing the covering rigidity and improving the bond — to limit subbase deformations.

4.2 *Two fundamental types of the failure of fixed-edge (arching) coverings are:*

a) vertical bond detachment followed by abrupt lifting up with raking;
b) joint crushing or breakage of ceramic tiles.

Both failure types may be produced experimentally. Our models made with conventional mortar failed according to the first type. Surface detachment was local, gradually spreading — lifting to some mm — at last, the covering "blasts". Obviously, the specified ultimate deformation belongs to lifting up.

Lifting up — buckling — may be attributed to bedding slope.

The resulting normal stress is:

$$\sigma = \pm \frac{6E_a \cdot E_f \cdot t_f \cdot \vartheta}{L_f}$$

where, in addition to symbols above,

L_f — length of a covering tile;
ϑ — bedding slope ($\Delta t_h/L_f$);
Δt_h — mortar thickness difference over a length L_f.

From this relationship it is clear that less (!) rigid coverings are more prone to lifting off, and in this failure type, subbase deformation has only a linear effect.

Bond strength of up-to-date — technologically correct — adhesives is much higher than that of mortars ($\sim$70 to 100 N/cm^2). In course of the tests, these coverings did not fail under service conditions but only upon ultimate deformation, according to failure type b) above.

Measured ultimate deformation values for the tested various covering types have been compiled in Table 1.

4.3 *Also coverings on tensile flanges of r.c. structures* have been tested. No tested covering type was found to be damaged on crack-free concrete subbase (up to 0.2‰ strain). The structural cracks after 0.03 mm appear also on brittle coverings practically the same width. The crack propagates in the covering either causing local detachments, step-wise along the joints (stoneware tile + + mortar) or, depending on the crack location, it may crack the tile (Fig. 3).

Table 1

Ultimate deformations of coverings

DYNAMIC TYPE	COVERING TYPE	MORTAR	EDGE MOTION 10^{-3} mm	ε_H ‰	MODE OF FAILURE DESCRIPTION	MODE OF FAILURE CONFIGURATION
A free edge	stoneware tile	Ha 10 15 mm	60-70	0.3-0.4	shear concrete-mortar detachment	
	wall tile		70-80	0.4-0.6	shear covering-mortar detachment	
B fixed edge	stoneware tile	Sziletor 2-3 mm	70-80	0.6-0.8	shear cover-adhesive detachment	
	wall tile		65-75	0.9-1.1	shear concr-adhesive detachment	
C clamped	stoneware tile	Ha 10 15 mm	—	0.6-0.7	lifting off raking	
	wall tile		—	0.9-1.2	lifting off raking	
	stoneware tile	Szileton 2-3 mm	—	> 1.0	1. joint material crushing	2 1
	wall tile		—	> 1.0	2. tile break	

Accordingly, soundness of a covering on the tensile flange is protected by respecting crack width limits in the structure. To prevent tile rupture (cracking only through joints), the covering has to meet inequality:

$$\frac{L_f}{t_f} < \frac{2R_{tu}}{\tau_R}$$

where R_{tu} is tensile strength of the tile.

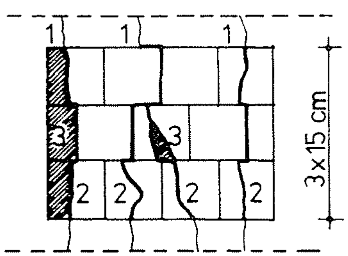

Fig. 3. Cracks of covering on the part in tension. 1. cracks of structure; 2. cracks of covering; 3. detachment

5. Further factors affecting the covering behaviour

According to the tests, adhesives are in the plastic range for most of their load capacity. This is an important reserve compared to the elastic range, favouring smoothing of stress peaks.

Another consequence of plastic behaviour is the sensitivity of bond coverings to repeated loads. Under repeated loads, forms of failure are exactly the same as under static loads for covering failing both in shear and in raking, but failure may also be induced by 20 to 60 times repeating a lower deformation level depending on the covering type and the load level.

Joints are primarily required by utility aspects, but they affect also the stress pattern of the covering. Because of a lower modulus of elasticity, joints absorb covering deformations in a proportion exceeding their share by width, indirectly reducing thereby covering stresses. In the plastic range, joints absorb nearly all the further deformation. Thus, an increased width improves the covering deformability, this is why recent building codes recommend wider joints. Excessively soft and wide joints act, however, as motion joints, and may entrain local detachments as free covering edges.

Deformometry showed the capacity of the covering to follow subbase strains to an important degree. Deformations of 0.3 to 0.4% have been measured on stoneware, and 0.7 to 0.8% on tiles, corresponding to 2 to 2.5 kN/cm^2 of normal stresses. This fact testifies that in certain cases the covering unit may itself rupture (conchoidal fracture), on the other hand, the interacting covering may absorb much of the loads on the structure, reducing thereby its deformation. In certain cases this favourable effect may be taken into consideration in ultimate deformation values.

6. Utilization of test results

By way of the research, the problem of ultimate deformation values for the most common brittle covering types could be answered. Ultimate values mean overall deformation after placing the covering, entraining failure of the covering.

Numerical values point out that the possibility of deformational damage of the covering cannot be ignored. The relevant structural deformation of 0.3 to 1.0% order may occur in use, justifying the requirement for limitation.

Test series results may indirectly be applied to prevent damages due to other than structural displacements. Namely humidity, temperature changes and shrinkage may expose coverings to further deformation constraints, and the structural soundness is only safeguarded if the complex of deformations due to simultaneous loads and other causes does not exceed the ultimate value.

The different effects may be converted to structural (subbase) deformations:

— subbase deformations of physical origin (e.g. shrinkage) may be added to displacements due to working loads;

— covering elongations (swelling, thermal expansion) correspond to subbase deformations of the same size but opposite sign:

$$\Delta\varepsilon_a = -\Delta\varepsilon_f \ ;$$

— the value of the elongation proper to the bedding layer, mortar (e.g. shrinkage) is converted as:

$$\Delta\varepsilon_a = \Delta\varepsilon_h \cdot \frac{t_h \cdot E_h}{2t_f \cdot E_f} \ .$$

Thus, resultant of different, simultaneous effects may be produced by simple addition!

Thereby limitation of structural deformations may be harmonized with expected building physical effects.

Comparison of deformabilities of covering types under test points to the extreme dependence of deformability limits on construction and on materials. Thereby no general ultimate deformation values for coverings can be specified. At the same time, empirically founded theoretical relationships offer a possibility to preassess the behaviour of a covering in knowledge of its dimensions and material characteristics.

Summary

Coverings fastened to, and dynamically interacting with, structures may be damaged by deformations of the loaded structure, to be avoided by limiting structural deformations or by selecting a proper cover type in knowledge of the stress pattern.

At the Department of Strength of Materials and Structures, T. U. B., test series have been made to determine the stress pattern and ultimate deformation of some typical brittle coverings directly fastened to the structure. Experimentally determined ultimate deformations of various coverings presented in the paper showed covering damages due to structural displacements often under service loads.

Another chapter is spent on the analysis of cover stress patterns. Relying on deformometry, suggestions have been made on the calculation of covering behaviour, taking also the effect of other than load-induced deformation constraints (shrinkage, swelling, thermal expansion) into consideration.

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* In Hungarian.