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ESTIMATION OF STIFFNESS ON THE BASIS OF THEORETICAL AND EXPERIMENTAL RESULTS OF PT SLABS WITH BIG SPANS

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1. INTRODUCTION

Application of post tensioned slabs began in America in early 60-ies, and used in Europe several years later. Generally, the principle consists in applying prestressing load in slab, which, beside the membrane compressive component, achieves the effect of counter load perpendicular to the plate. This is achieved by keeping the shape of tendons line within the slab which deflecting forces act in the direction of tendons curvature. Technical and economic advantages are reflected in the wider span and with a slenderer slab dimensions. Reduced initial deflections (sometimes is the initial elevation in calculation), but predominantly compressive stress in the slab with localization of boundary tensile stress has a beneficial effect on reducing long-term deflection. Since the application of prestress force, perform 3 days after concreting, that's why the speed of construction is faster because the formwork can be removed.

The smaller weight of slabs take beneficial effect related to the seismic and foundation design, and because of reduction of slab thickness achieved a smaller volume. Considering steel cable contact with concrete there are two types of tendons. The first case is when between the cable and the tube is injection mixture ("bonded tendons"), and second, this case, is when the rope in a plastic tube with a protective fat ("unbonded tendons").

In Croatia, this technology began to apply in year 2005, predominantly by using of unbonded technology (Fig. 1) because of the speed and ease of installation, operation in winter conditions and the possibility of concreting large working strokes due to small losses of friction.

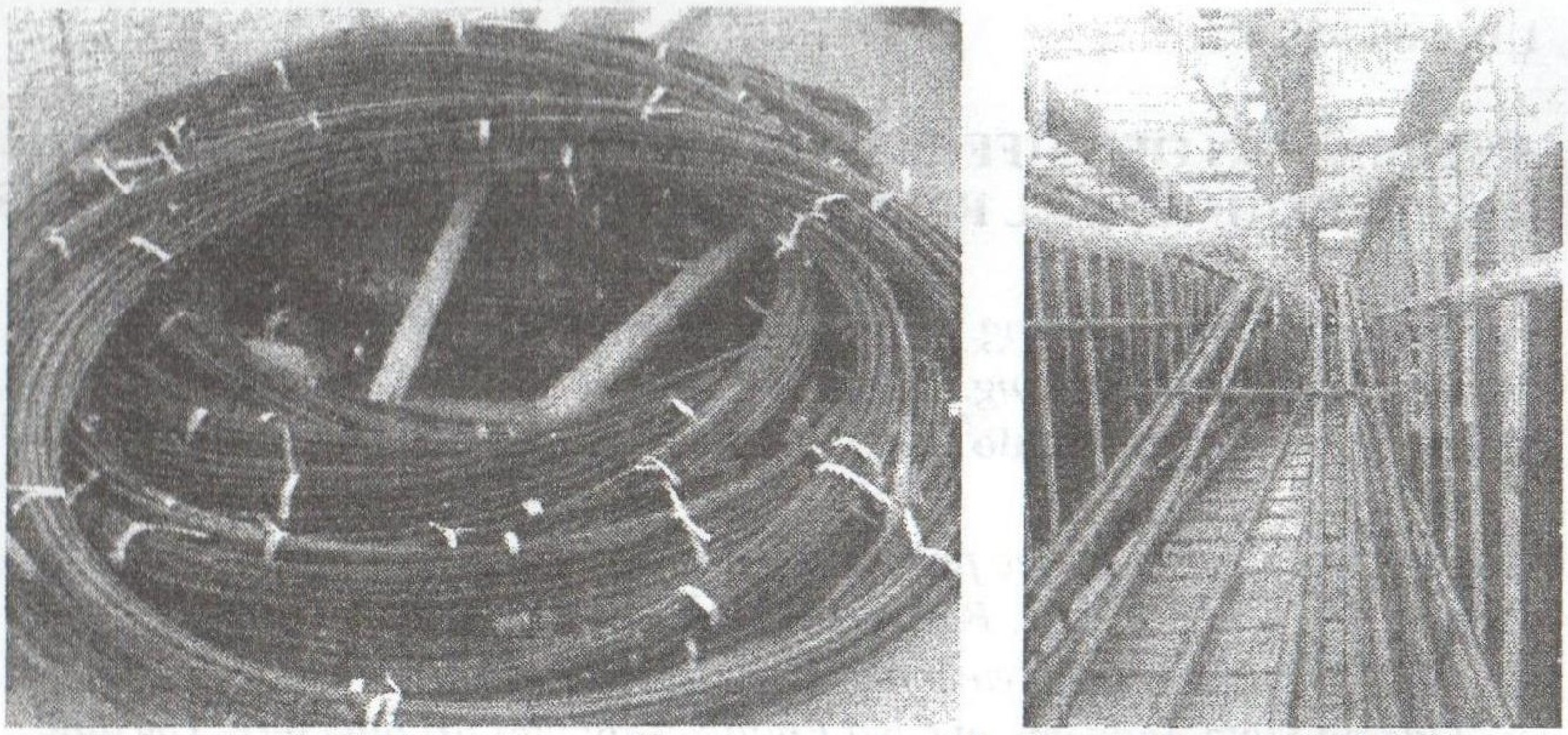

Fig. 1 Cable without direct contact with concrete and steel (unbonded tendons)

2. DESCRIPTION OF GARAGE CONSTRUCTION

Underground public garage is a ground plan dimensions 77 x 79 m with 443 parking spaces (Fig. 2). Total area of two underground levels are 12 370 m^2. Above the upper slab will be a 1.0 m height layer of the future town square. Base slab and the walls are the classic RC structures, while the ceilings are PT slabs. Central slab is loaded only by traffic operation has beam sizes 50/60 cm between which the slab which is 16 cm thick.

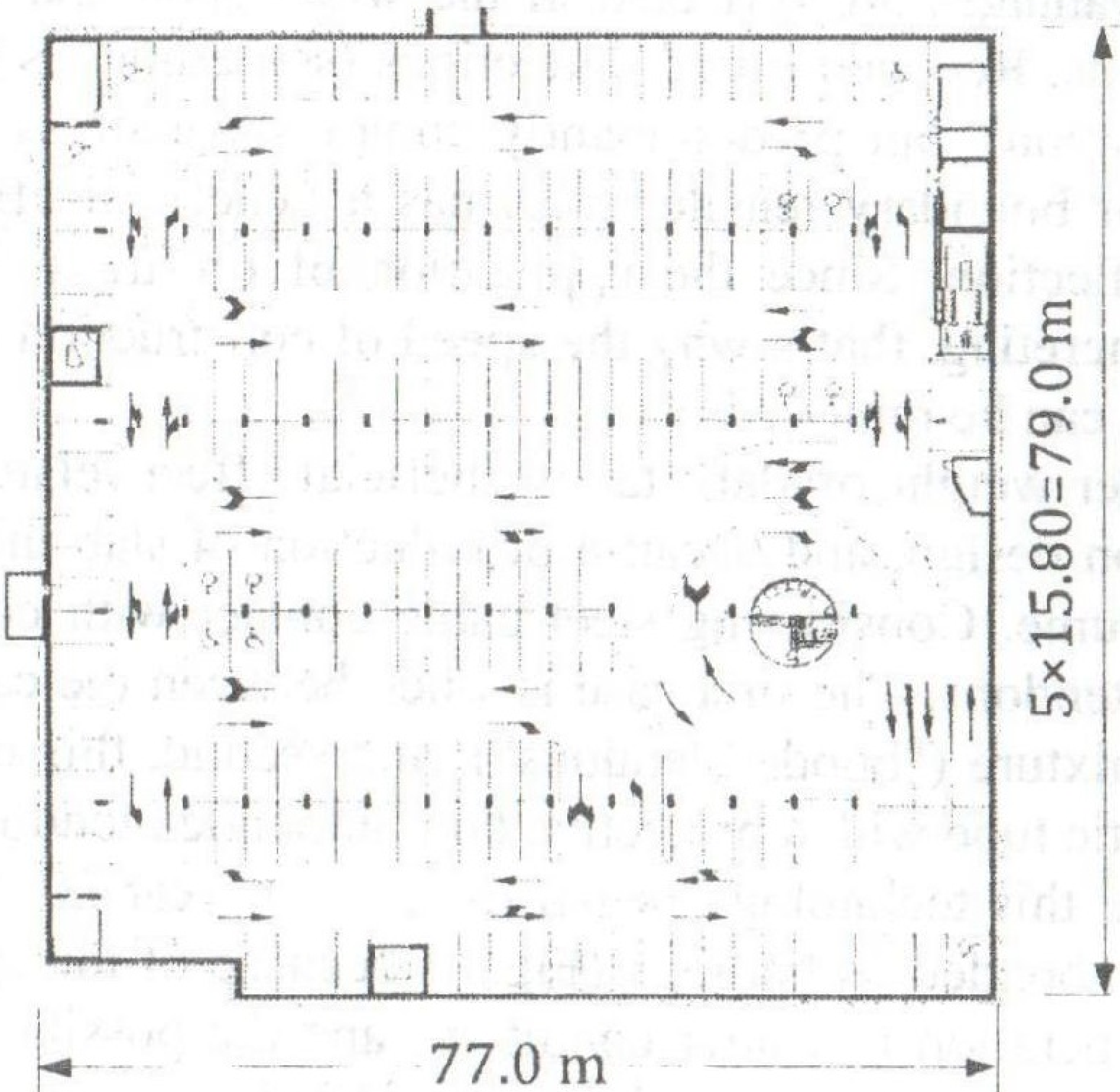

Fig. 2 Plan of garage ground-floor, columns with spans 8.15 x 5.0 m

The upper slab beam carries much greater loads (DL + layers + traffic = 8.5 +18.0 +7.0 kN/m2) and has dimensions 75/90 cm with slab 24 cm thick. The groundwater level is slightly above the middle slab level, and the construction in dry environment ensures the continuous pumping of water by wells, this solution showed better than originally planned injection of subsoil.

3. DESCRIPTION OF CALCULATION MODEL ON ANALYSIS OF CHARACTERISTIC SECTION

A characteristic section width is 5.0 m (Fig. 3) and a length two and a half field (2.5 m × 8.15 m = 39.5 m). The goal is to determine the design model that will give more accurate results of deflection and stress conditions. Experience shows that the simplifications that are applied in the calculation programs on the market provide multiple differences in the results that, for example, the difference by applying various regulations.

Fig. 3 Model of characteristic section for the analysis

More so is because behavior of PT slabs is a lot closer to calculation by theory of elasticity because of reducing concrete cracking areas. On analyzed model of characteristic section with symmetry boundary conditions, the main thing is to determine the proper interaction of the finite element beam and slab and model prestressing load (Fig. 4). Because the slab is not absolutely rigid by shear, there is a lag of longitudinal strain in the slab (the effect of "shear lag").

Simplifying a complex T-section by stick model (Model A), with the barycenter position of neutral axis and constant longitudinal stress of slab boundary, can not include this effect. Determination of an influential width of T-section is a complex problem treated differently by various regulations, with a number of factors that affect the width of an influential width of slabs in the joint zone and field zone (the relation of dimensions of slab and beam, and their grids raster and span, method and positions of slab supporting, place of the load on plate ...). And with various simplification of this problem through literature and regulations, remains problem of slab behavior between beams which are in longitudinal direction a kind of elastic supports for the slab. Solution of modeling by finite element method is on a better way, but remains question of interaction of stick and slab element (Fig. 5). Specifically, placing both elements in a same plane (model B) underestimates the stiffness of the system, because of this assumption neutral axis (for vertical load) remains mutual in the middle of the stick and slab elements. Similar situation occurs if instead stick element put an element of slab with greater thickness. The consequence of this situation is unrealistic stress condition of upper and lower edge of the slab without compatibility of longitudinal stresses in the jump zone.

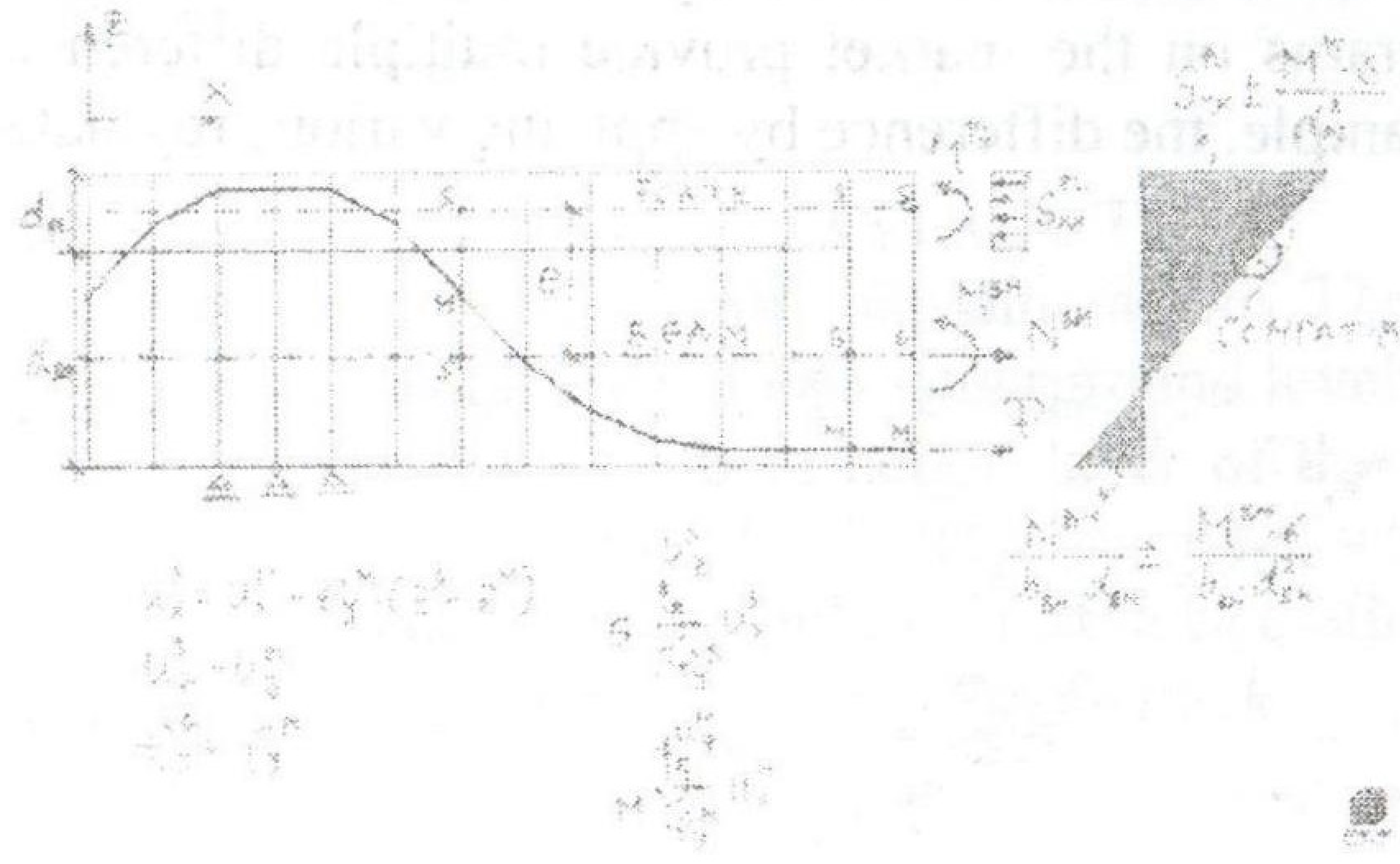

Fig. 4 Theoretical setting of eccentric nodes kinematic connection

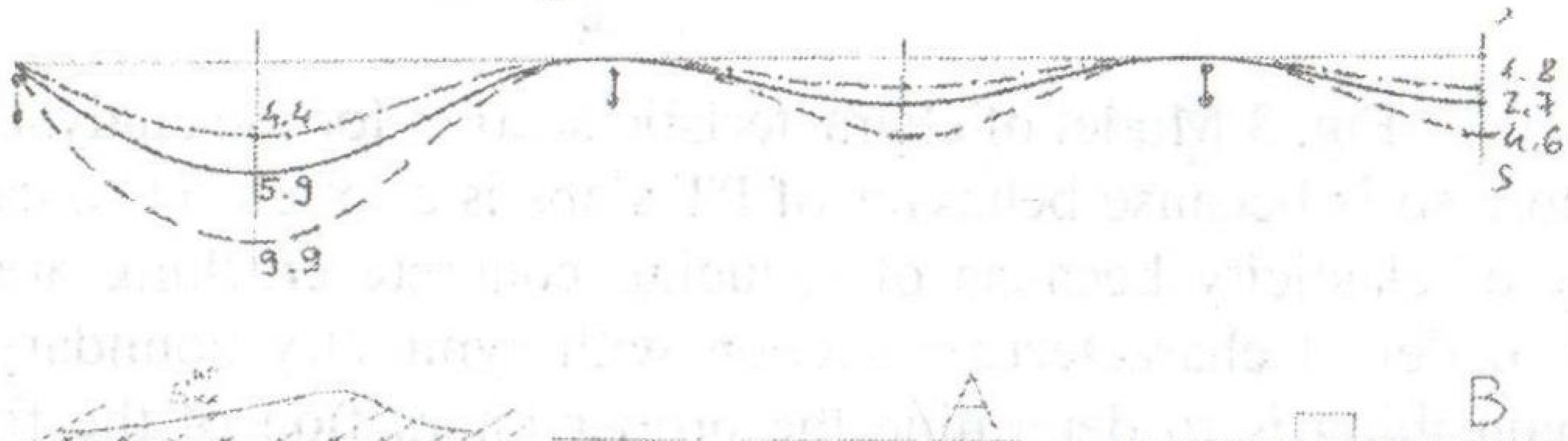

Fig. 5 Alternative models A and B for comparison (dead weight load)

In reality, neutral axis changing the height along the girders and transverse in section, and in rib zone is located around the lower edge of slab. Of course in such a model prestressing load (including the P·e effect) can not give real deflection and stresses. Some programs offer a solution with fictitious increasing of beam height and intervention in the matrix of elasticity of such element. In this way may be obtained closes state to realistic stiffness, but still there remains the problem of unrealistic boundary stresses. In author's solution in GRAFeM computer program, this issue solved by eccentric position of the nodes of slab element to nodes of barycenter of sticks elements and their kinematical connections (master-slave options). Kinematic condensation of master and slave nodes establishes their equal translational displacement while the relationship of the rotation displacement is linear.

This is true if consider assumption of vertical incompressibility of slab, small displacements and sections are flat after deformations. While in this case number of equations in the global stiffness matrix was not increased. The problem of prestress load modeling is also resolved by kinematical connected eccentric nodes in which, by default layout form, passing stick elements negligible stiffness with default prestressing force. Therefore, the prestressing load is resolved at a general level by the geometry of fictitious sticks at discrete points, without analytical formulas to determine the components of pressure and deflective force which are a function of tendons curvature. When summed, the components of prestress forces are in equilibrium. Figure 5 shows differences in the deflections of our model to the variant models A and B showing that in the model A stiffness is overestimated by around 1/3, while in model B underestimated by about 2/3 of the amount. Here are some selected pictures from the calculation analysis and summary longitudinal stresses of the upper and lower edge of the beam and the upper edge of slab with a pronounced shear lag in zones of supporting (Fig. 7).

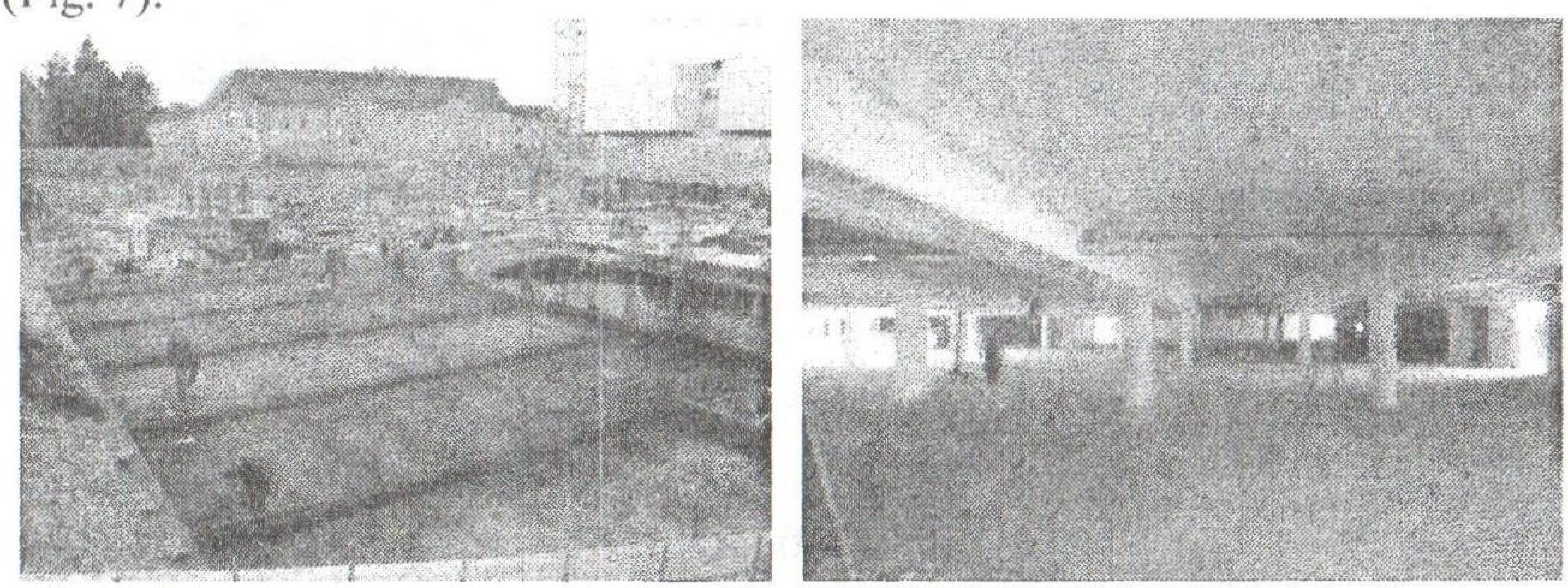

Fig. 6 Constructing and arranging of underground garage interior

The analysis shows that the stresses of upper edge value is below allowable tensile strength of concrete (f_{ctm} = 2.9 MPa for concrete C 30/37) for the maximum vertical load and the lower edge of the beam for dead load and constant additional layers load. Time deflections of rheology do not exceed L/500 of the span. Nonpresstresed reinforcement is determined on the effect of membrane forces and bending moments with the partial safety coefficients according to EC2 regulations.

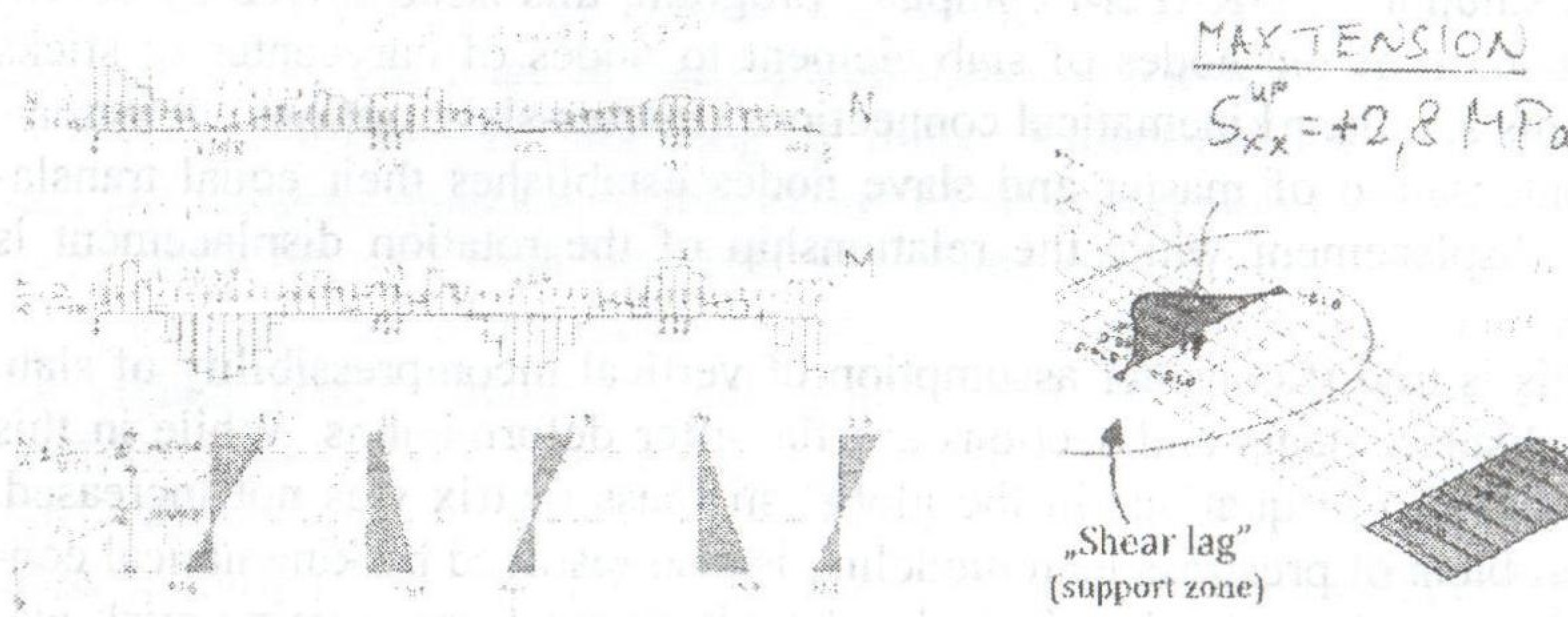

Fig. 7 Stress state of the beam (load $g+g_1+0.9P$) and the slab ($g+g_1+q+0.9P$)

4. CONCLUSION

With the approaching of work completion estimation of stiffness was done by measuring the beam deflection to confirm the accuracy level of theoretical results compared to actual. First measure of the beams lower edge deflection is analyzed on the load increment of 60 cm thick gravel mound. Fig. 8a shows good matching with analyzed theoretical model. Deflections of the first field would be higher if at the time of measurement gravel mound was not finished 3-4 meters before the edge of the wall.

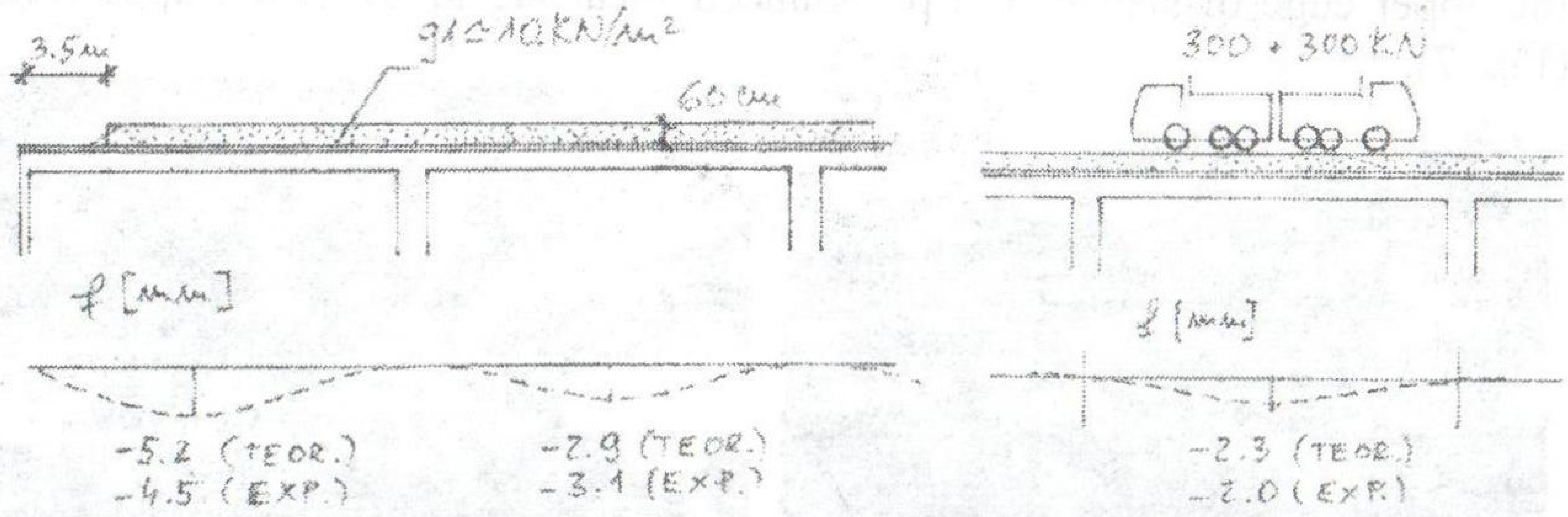

Fig. 8a i 8b The deflection test of the beam with mound gravel thick 60 cm and traffic test load

The second measurement was done for the moving load, it was two trucks with a load of gravel so that each weighs 30 tons. Position is selected so that beam line is maximally loaded in the first field, and then in another field (Fig. 8b). Again, this results of measurements confirmed the correctness of the calculation model. After unloading, residual deflections were 10-15% (this is the zone that close to the limits of accuracy of the measuring geodetic device).

Summary

On example of publics building "Capuchin Square" construction pit in Varazdin (Croatia) is shown analysis method of PT ("Post Tensioned") slab with control measurement of test load. The garage is designed in a very successful way for take up of the number of parking spaces, within 16 meter of span obtained quality and commotion in the parking avoiding pairs of columns in the spans middle. Typical bearing elements of PT slabs are monolithic beams over 5 fields with columns span of 15.8 m and 5.0 m grid. Tendons layout in the direction of the larger span is within the beams while in the perpendicular direction through the slab at uniform intervals. FEM model calculation was applied on the eccentric distance of nodes of beams barycenter and nodes of mean plane of the slab between which have been established kinematic connections. Comparative analyses have shown that in the simplified calculation treatment are possible considerable discrepancies in the estimation of stiffness and stress conditions. Estimation of model validity is confirmed by measurements of beam displacement for different load cases.

Literature

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