USE OF ANALOG GROUND MEDIUM OF TAYLOR-SCHNEEBELI TYPE FOR MODELLING OF MULTIPARAMETRIC DEFORMATIONS ARISING IN MINING-INFLUENCED AREAS[1]

by

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Abstract: The results of the author's several years of model research using analog ground medium of Taylor-Schneebeli type to the multiparametric simulations of mining area deformations are presented in the paper. On the basis of the model similarity criteria the complete usefulness was proven of this research approach to the analysis of process of joint action of the mining rock mass and ground structures, underground infrastructures, engineering structures and road surface, also with use of geosynthetics.

Additional Key Words:
- model similarity criteria
- ground analog
- model research
- mining substrate
- kinematics of the disintegrated medium.

Introduction

A number of phenomena happening inside the rock mass and on its surface are impossible to record and to conduct direct surveys of analyse or research on the theoretical grounds. This is due to technical and economical reasons, as well as space-time limitations. Under these circumstances model research, conducted with the use of the equivalent and loose material, is gaining importance. The use of the equivalent materials (sand, gypsum, lime, borax, water mixtures, etc.) requires suitable selection of material constants in order to maintain the similarity laws. As a final result, this research allows to analyse not only the dislocations and deformations, but also forces and stresses occurring in the medium. Although the main domain of its application is ground and exploitation excavation areas [16], it remains beyond the scope of this paper. Models built of media, especially of sand allow conducting research limited to the kinematics of medium reduced to the recording of dislocations and displacements in the medium, caused by initially inflicted limiting displacements. Each of these groups of research has its advantages, but also substantial disadvantages. The paper presents a compromising approach to this problem which connects basic advantages of both main research trends by using the so-called Analog Ground Medium of Taylor-Schneebeli Type [8,15]. The possibility of full optical recording of undisturbed character of deformation of mining area surface and structures on the subsoil is given special consideration.

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THE CRITERIA OF MODELLING SIMILARITY

There are two basic rules of modelling similarity in the model research. The first one is the rule of geometric similarity based on fact that dimensions of modelled space are in proper relation (modelling scale) to the real object. The second is the rule of mechanical similarity, in form of three conditions:

- kinematic model similarity,
- dynamic model similarity,
- rheological(time) model similarity.

The kinematic similarity condition require the relative dislocations of the corresponding points in the model and in nature to be in geometrical interdependence. The comprehensive preliminary research proved [4,6] that corresponding parts of superficial zone of rock mass and of the Taylor-Schneebeli model are the subject to the same linear and formational deformations under identical excitations. For the process of modelling of dislocations of the surface of mining area for dynamic subsiding through, the conformance is shown in Fig.1.

The description of the profile of the subsiding through appearing on the surface as a result of the simulated exploitation show a full correspondence to the Gauss curves (normal distribution curves). This corresponds to the recorded distribution of real effects in the ground [9,10,16]. The other dislocations and deformations, which describe basic deformation parameters of surface, such as depression (W), sloping (T), curvature (K), horizontal dislocation (U) and unitary horizontal deformation (ε) are also fully corresponding. The theoretical shapes of these functions and their interdependence are shown, among others, in [2,3]. The fulfilment of this principal kinematic criterion of similarity guarantees the proper simulation of the behaviour of model surface objects founded on the ground analog T-S (Taylor-Schneebeli) type and related to the planar problems. The condition of dynamical similarity requires the ratio of model and real forces be the same as the ratio of mass and accelerations product, described by the relationship:

$$\frac{F_N}{F_M} = \frac{m_N \cdot a_N}{m_M \cdot a_M} \qquad (1)$$

where: a_N -acceleration of mass m_N

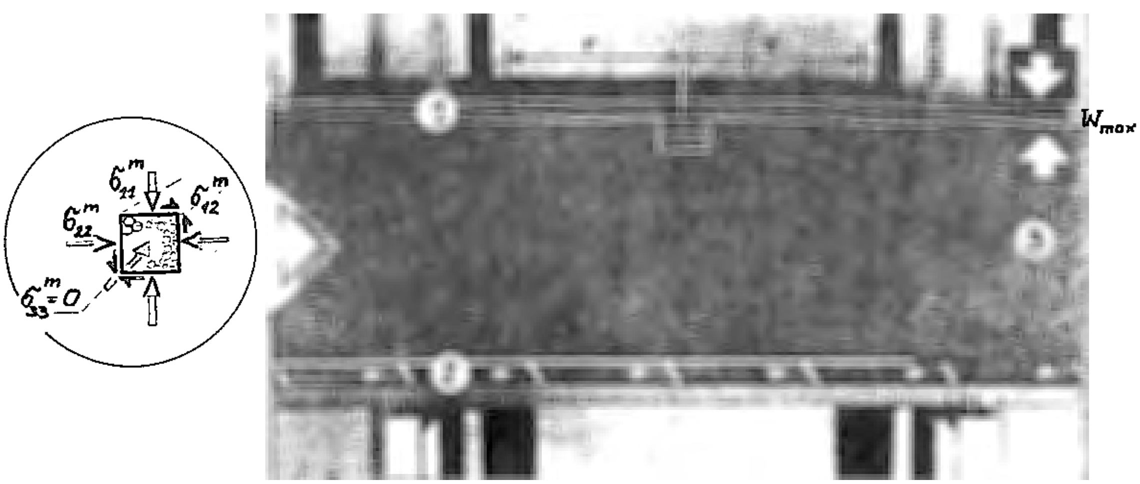


Figure 1. Dynamic subsiding through of a depression
(1) for variable position of exploitation front
(2) in an analog model of rock mass
(3) Taylor-Schneebeli (T-S) type.

under the force F_N in nature.
a_M -acceleration of mass m_M under effect of force F_M in the model.

This condition implies the constant value of the unit mass ratio, the masses being different by the factor b:

$$b = \frac{m_N}{m_M} = const \qquad (1a)$$

In the case of T-S type analog this factor is b=1. The condition of rheological similarity requires that the quotient of deformation velocity in nature and in laboratory was a constant value:

$$\frac{\dot{\varepsilon}_N}{\dot{\varepsilon}_M} = const \qquad (2)$$

Because the tested model was a granular rock medium and its cohesion was zero, this criterion was easily met. The physico-mechanical parameters of the materials used as equivalent should fulfil a number of additional conditions,calculated theoretically basing on the rules of modelling similarities. However, obtaining the wanted values of most of the parameters is very difficult and practically currently not possible. Therefore in practise the rule of functional characteristic is applied. It assumes as a basis of the mapping such mechanical index, which in analysed phenomena plays a vital role. It has been assumed that the principle will concern the preservation of the similarity of the phenomena of ground shearing as a basic strength criterion for this dispersed medium.

THE DESCRIPTION OF THE ANALOG GROUND MEDIUM.

The T-S type analog medium consist of a mixture of cylindrical rollers of two diameters: Ø4mm and Ø6mm, L=47mm long and weight by volume of γ=1.4G/cm^3. The side surfaces of the rollers are fine finished, ensuring the full stability of the pile, which then not need head walls. The assumed ground model ensured exactly flat state of strains and deformations. The Schneebeli's experiments [15] have shown that the pile of circular rollers of different diameters fulfil the condition of Coulomb's limiting equilibrium [12,13] . The necessary condition for obtaining the macroscopic and isotropic structure of the medium is the use of a set of rollers of different diameters [1,11]. Deformations of the single-fraction medium have discrete character, caused by structural anisotropy of the homogeneous pile. The anisotropy of the structure leads to the law of anisotropic elasticity of the analog making the research difficult and its results hard to interpret. The example of that is presented in interpret [7]. The conditions of model similarity of the mixed task require the fulfilment of adequate dependencies between strains, weights by volume, strength and geometric parameters of the model and the real object. This can be described as:

$$\alpha_\sigma = \alpha_\gamma \cdot \alpha_L \cong 1$$
$$\alpha_\gamma = \frac{\alpha_\sigma}{\alpha_L} \qquad (3)$$
$$\alpha_\phi \cong 1$$

where: $\alpha_{\sigma,L,\gamma,\varnothing}$:the scale of strains, lengths, weights by volume, internal friction angle. After substitutions it is possible to describe the state of strains in nature on the basis of the ground analog parameters:

$$\frac{\alpha_\sigma}{\alpha_L}\left(\frac{\partial\sigma_{22}}{\partial x_2} + \frac{\partial\sigma_{12}}{\partial x_1}\right)m = 0$$
$$\frac{\alpha_\sigma}{\alpha_L}\left(\frac{\partial\sigma_{11}}{\partial x_1} + \frac{\partial\sigma_{12}}{\partial x_2}\right)m = \alpha_\gamma \cdot \gamma_m \qquad (4)$$
$$\frac{\alpha_\sigma}{\alpha_L^2}\nabla^2(\sigma_{11} + \sigma_{22})m = 0$$
$$(\sigma_{11} - \sigma_{22})m = (\sigma_{11} + \sigma_{22})m \cdot \alpha_\varphi \cdot \sin\varphi_m$$

The parameters with index „m" correspond to the model. The first two equations describe the limiting equilibrium state, the next concern the condition of inseparability and the Coulomb-Mohr plasticity criterion. The homomorphic model of T-S type ground does not meet exactly all of the similarity model conditions. The research results are burdened with certain errors resulting from non-fulfilled criterion of that weight strain scale and geometric similarity of grains criterion. However it does not influence significantly the results, especially of the preliminary, qualitative estimation of the investigated effects of interrelation of structure and mining deformed ground.

USE OF THE ANALOG GROUND FOR THE MODELLING OF THE INFLUENCE OF UNDERGROUND MINING ON SELECTED OBJECTS ON SURFACE

The research carried out by the author using the T-S type analog medium preceded the complementary and verifying experiments realised with the use of sand in a specially constructed box apparatus (Fig. 2, [14]).

This apparatus made possible the physical realisation of the basic index of mining deformation of a terrain. The index were the unitary horizontal deformations of compacting and slackening character ε.

The direct recording of the kinematic effects and verifying the computational models was in this case impossible. Only the T-S analog placed on a specially constructed research stand shown in Fig. 3 makes the recording of these effects fully possible. In the model shown in Fig.1 the displacement of the working face of underground exploitation is simulated by the stages of sliding of a batten in the bottom part of the T-S pile. The contrasting (white) rollers of the T-S pile make possible clear dynamic recording of the freely chosen points of the medium. The research stand creates the possibility of simulation of all the deformation parameters in the near-surface zone as well as in the rock mass.

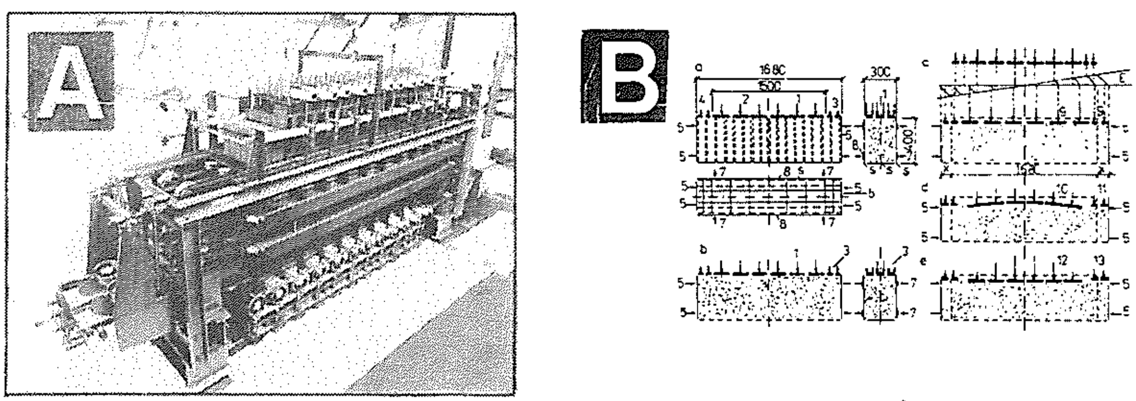


Figure 2. Apparatus for modelling of horizontal mining deformations in loose granular medium
A) General view
B) Principle of apparatus operation taking under consideration an external load.
Denotations: 1-2: vertical load, 3-4: horizontal load, 5-8: head-walls and side-walls, 9: flexible load, 10: stiff load.

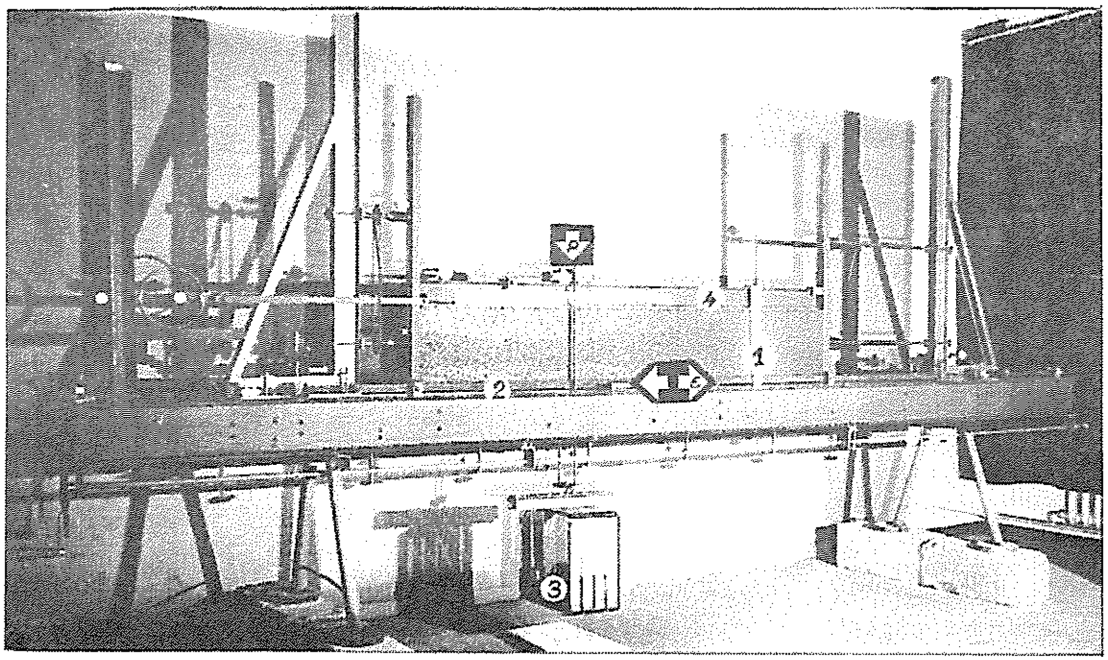


Figure 3. Test rig for modelling of the mining deformations in T-S type analog medium.
Denotations: 1: T-S analog, 2: rubber band, 3: external load, 4: model of the foundation.

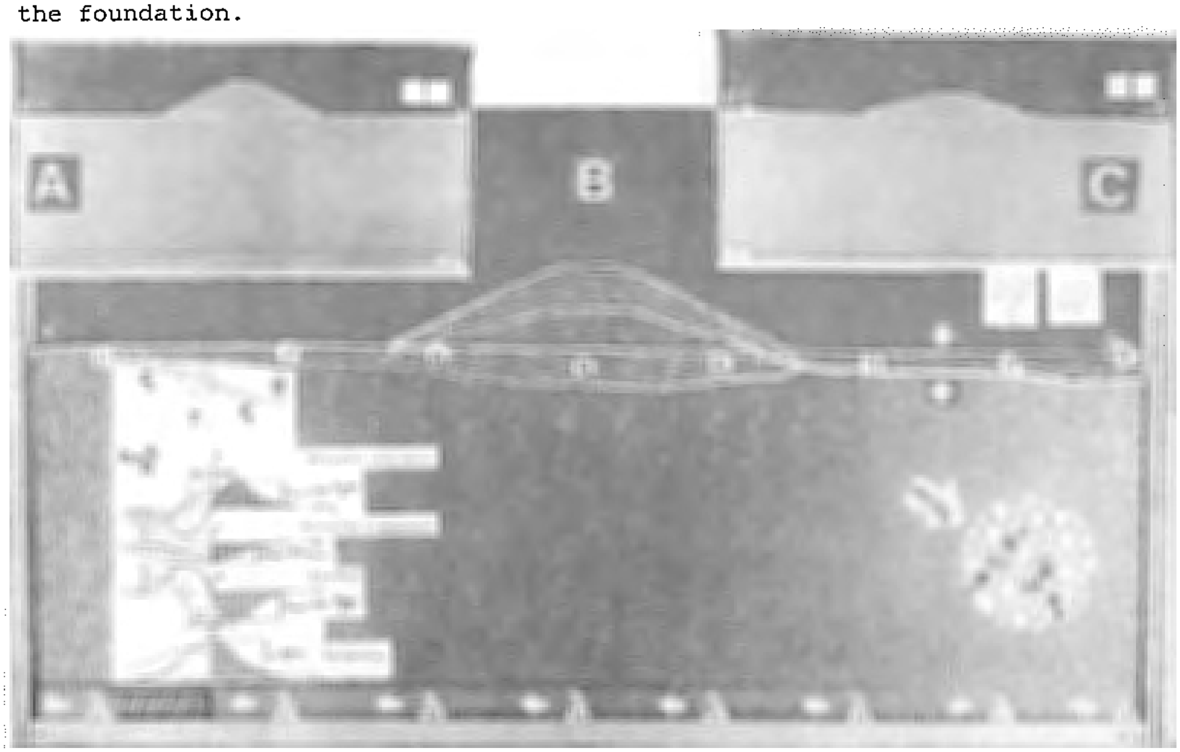


Figure 4. Modelling of the mining deformations within an embankment earth construction
A) Initial state
B) Passing of dynamic subsiding trough under the object, perpendicularly to its longitudinal axis,
C) Final state, after the excitations have ceased.

The research stand shown in Fig.3 makes possible the simulation of the main index of the mining deformation, i.e. the unitary horizontal deformation ε of the compacting and slackening character. The container filled with T-S pile has in its bottom part a rubber batten stiffly attached to the properly bedded side walls. The central drive makes possible exerting a uniform tension on the rubber belt and eventually creates a horizontal simulation of homogeneous deformations ε, typical for a mining area. This apparatus additionally makes possible the simulation of the vertical curvature of the bed K, both concave and convex.

The most important and fully successful tests of application of T-S analog for geotechnic applications in mining-influenced areas include:

- modelling of the deformations arising in mining-influenced areas caused by underground mine exploitation together with the global assessment of the influence of the dynamic subsiding through, on the surface objects such as earth structures (embankments, cross-cuts - Fig. 4), tunnel constructions (Fig. 1), supports, etc.
- estimation of the influence of slackening horizontal deformations of the building foundations in wall footing or grillage systems (Fig. 5a), together with the assessment of the influence subgrade reinforcement on the reduction of additional axial forces in the wall footing - Fig. 5b.
- assessment of the influence of compacting horizontal deformations on the surface retaining constructions - Fig. 6a, b, and the constructions hollowed in the ground - Fig. 6c.
- the determination of the character of interrelation of the road surface and the permanent way with the mining-influenced area; a detailed investigation was carried out to find the sources of additional forces in the rails of the permanent way resulting from thermal effects and braking vehicles - Fig.7. The studies were also aimed at finding the sources of slackening deformations (Fig. 8) of the mining-influenced subgrade and determining the reinforcement of load capacity of track grillage subgrade by geotextile undersleeper containers and horizontal membrane - Fig. 9.

The detailed analysis of the results of this research is impossible to be presented here, because of the space limitations of this paper. More details concerning this subject may be found in [3,4,5,6,11] and other works.

The results of the kinematic research show the essential differentiation of the character of interrelation of structures with the mining-influenced areas opposed to the case of a non-mining area. As a consequence a necessity arises of a separate theoretical approach to this class of complex, interdisciplinary computational problems encompassing the issues of rock-mass mechanics, mining geotechnic and the construction theory. Without applying the described research techniques, it would be extremely difficult, if not impossible, to obtain the described results.

CONCLUSIONS

The application of the Taylor-Schneebeli type analog ground in a model research of mining substrate proved a number of essential advantages in comparison with the traditional models using equivalent materials and natural granular substances. The advantages are:

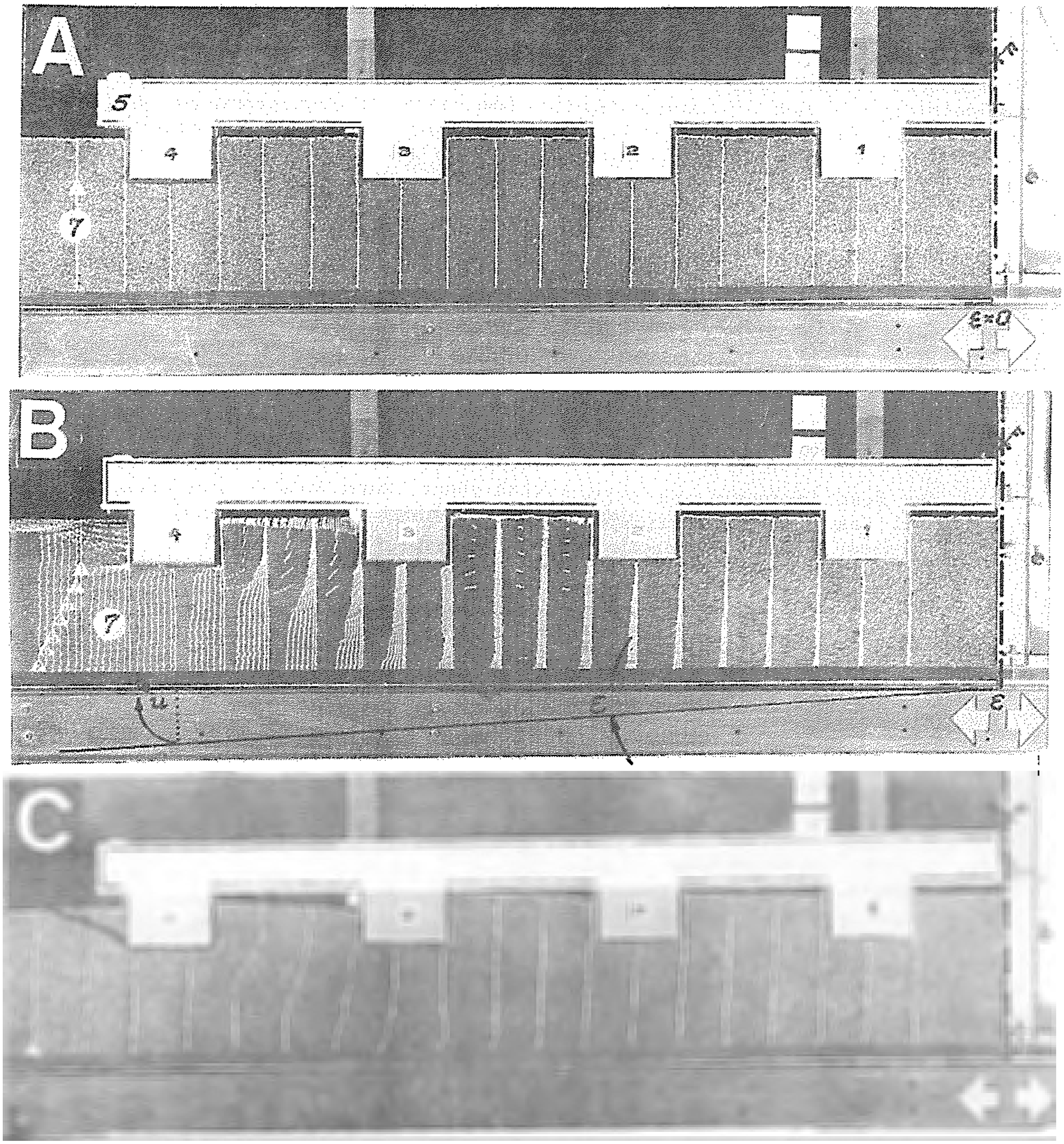


Figure 5. Modelling of the interrelation of the transversal foundation benches under the conditions of horizontal slackening of subgrade without reinforcement
A) Initial state
B) Growth of slackening deformations in mining subgrade
C) Final state, after the excitations have ceased
Denotations: 1-4: transversal benches, 5: longitudinal bench

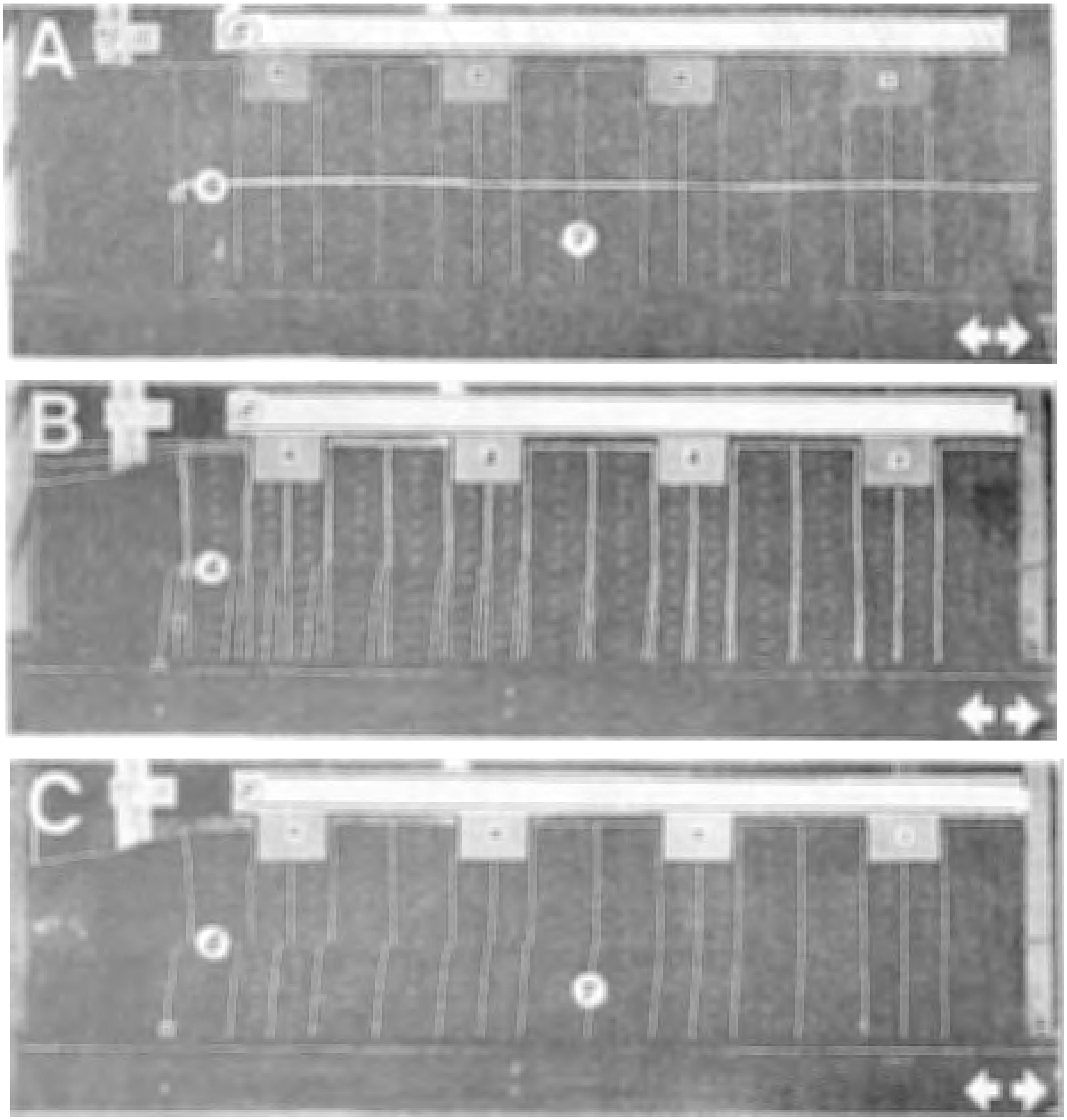


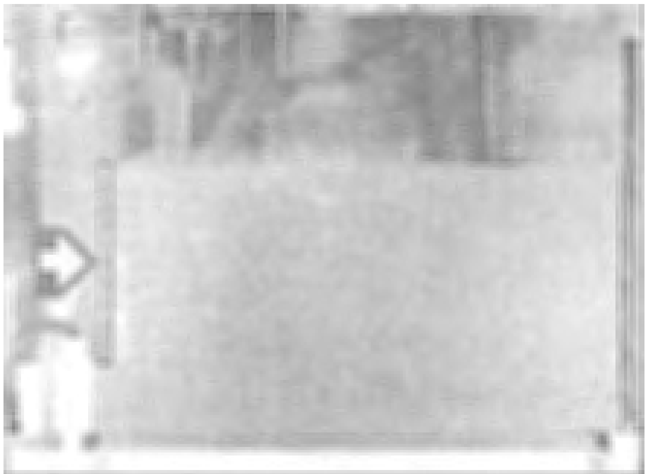
Figure 6. Modelling mining influences on transversal foundation benches under the conditions of slackening deformations of subgrade with geosynthetics strengthening

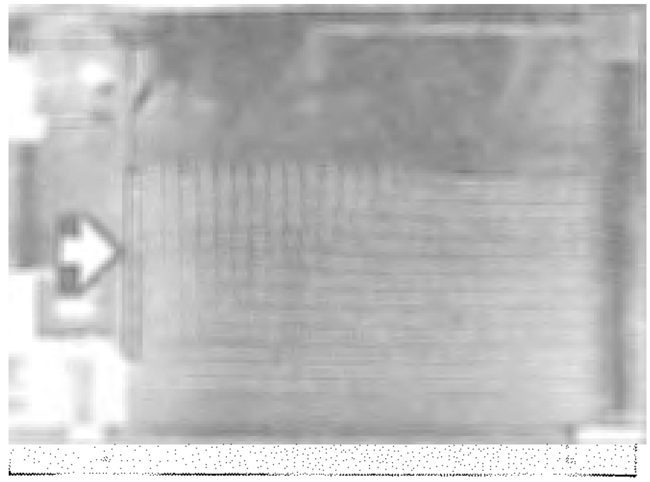
A) Initial state

B) Growth of slackening deformations in mining subgrade

C) Final state of deformation after the influences ceased

Denotations: 1-4 transversal benches, 5: longitudinal bench, 6: subgrade with geosynthetic strengthening, 7: contrasting elements of T-S pile.





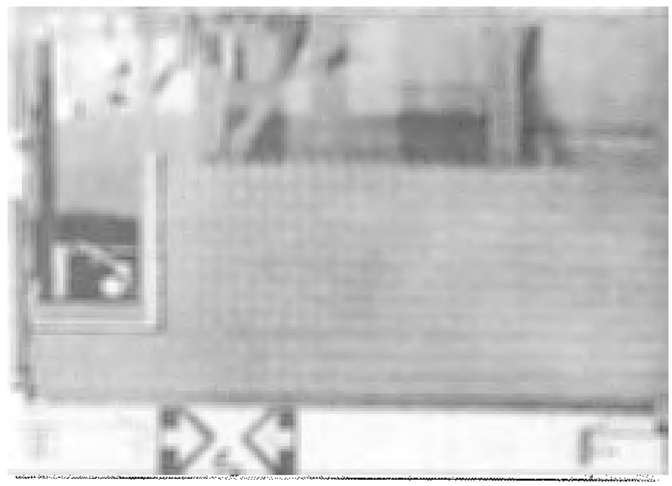


Figure 7. Influence of horizontal thickening deformations on the retaining constructions
A) Passive ground pressure without mining influences (shift of the construction towards the ground-left side, relative shift of the ground in relation to the construction-right side)
B) Pressure of the ground under the conditions of thickening deformations of mining subgrade with kinematic analysis (a-horizontal component, b-vertical component, c-resultant)

- comparatively simple construction of test stands of universal use, allowing the recording of the deformation field and the components of the stress state in complex flat state of deformation, recording being complete and undisturbed by the boundary conditions
- preservation of the main criteria of modelling similarity, creating the basis for the further qualitative and quantitative analyses. The adoption of the obtained results to the engineering practice is possible thanks the values of the scale coefficient α_i being close to those corresponding to the natural conditions.
- relatively short duration of the research and test programme, low cost of labour and apparatus and the consistently good repeatability of the results
- the characteristics of the phenomena of the dislocations and deformations in the rock mass and the sub-surface layer fully correspond to the qualitative representation of the same effects in the experimental research in T-S type analog medium. The latter statement concerns also the process of the interrelation with the surface objects located on the mining-influenced areas, also under different conditions of mining, for instance in case of strip-mining;
- the results of the research on the analog medium have mainly introductory and qualitative character. Therefore, the attempts to transfer directly the qualitative criteria to any real object should be considered with due care and attention.

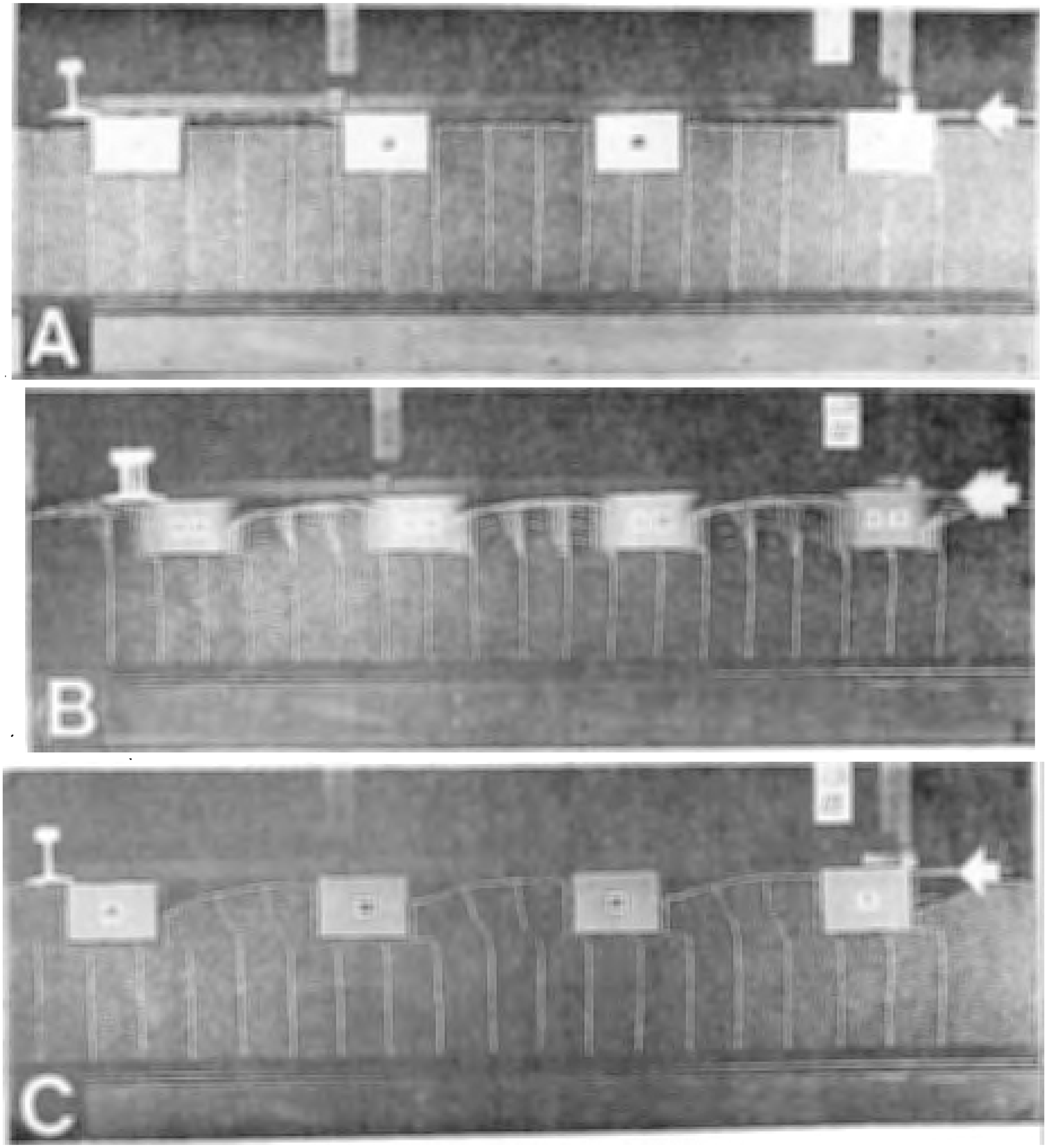


Figure 8. Modelling of kinematic phenomena related to the rise of axial forces in railroad track on the non-mining areas.
A-Initial state
B-Growth of the axial forces in permanent way (temperature, retarding of vehicles etc.)
C-Final displacement state

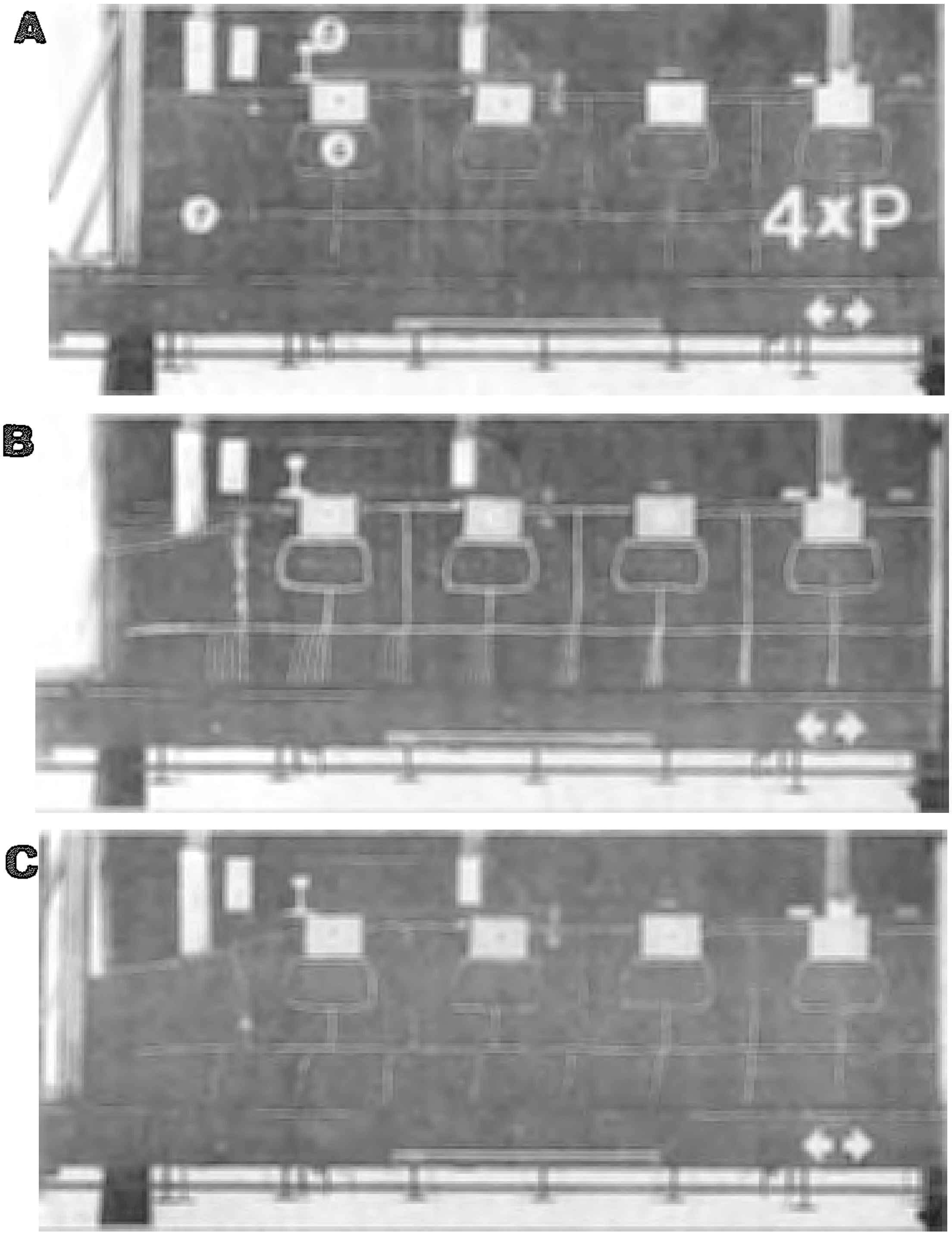


Figure 9. Modelling of the influence of slackening mining deformations on the permanent way strengthened with undersleeper geotextile containers and horizontal membrane.
A) Initial state
B) Growth of slackening deformations in mining subgrade
C) Final deformation state, after the influences ceased
Denotations: 1-4: sleepers, 5: rail, 6: undersleeper geotextile container, 7: horizontal geotextile membrane.

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