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Influence of Rubber and Mineral Admixtures on Selected Swelling Properties of Red Clay

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Abstract. Swelling and shrinking of soils is considered to be one of the main reasons of building damages. This problem concerns practically all fine soils in plastic or semi-solid consistency and becomes very intense in the case of montmorillonite or smectite clays. Reduction of soil expansiveness can be obtained by various methods: e.g. surcharge greater than swelling pressure or stabilization with additives such as lime, cement or polymers. In the last decades engineers have become interested in the use of waste materials in geotechnics, and thus such materials like fly ash, furnace slag or scrap tyre rubber are also now considered as valuable and eco-friendly admixtures that might be used to reduce expansiveness of soils. This paper presents a study on the influence of mineral and rubber admixtures on expansive properties of clay: swelling pressure $p_s$ and free swelling coefficient $V_p$. The experiments were conducted on red Triassic clay from Patoka in Poland mixed with rubber powder (0.1 – 1.0 mm) or granulate (1 – 5 mm). The rubber content applied was 10% by weight. Results revealed that admixture of rubber reduced the expansiveness of clay: $p_s$ decreased by 57% and 63% and $V_p$ by 11% and 57% when coarser and finer rubber fraction was used, respectively. In order to check whether the observed decrease in swelling properties resulted from compressive characteristics of rubber, additional specimens were prepared in which the rubber grains were replaced by sand or gravelly sand in the same proportion by weight and by volume. It turned out that the mineral additives can reduce the expansiveness of Red Clay even more effectively than rubber, proving that in this method of stabilization the mechanism of replacement plays more important role than the lower stiffness of the added grains. However, independently of the type of the additive, better results can be obtained when grading of the admixed material is finer.

1. Introduction
Alternating swelling and shrinking of soils is considered to be one of the main reasons of building damages that need costly repairs. This problem concerns practically all fine soils in plastic or semi-solid consistency and becomes very intense in the case of montmorillonite or smectite clays. Natural expansive soils (changing their volume upon wetting or drying) constitute a vast part of subsoil in many regions of the world [1]. For example in Poland they can be found in the superficial Tertiary and Quaternary deposits covering almost half of the country’s area [2], [3].

Reduction of soil swelling can be obtained by various methods that might be roughly divided into three groups: constructional like application of a surcharge greater than swelling pressure [4], chemical like stabilization with additives such as lime, cement or polymers [5] that change the nature of bonds or
mechanical based on complete or partial replacement (mixing) of the problematic soil with some other stable material or based on compaction or water content control (e.g. pre-wetting prior to construction). In the last decades engineers have become interested in the use of waste materials in geotechnics, and thus such materials like fly ash, furnace slag or scrap tyre rubber are also now considered as valuable, cheap and eco-friendly admixtures that might be used to reduce expansiveness of soils. Probably the first research campaign on influence of scrap tyre rubber addition to expansive clays was started in 2007 at Colorado State University. Seda, Lee and Carraro [6] proved that both the swelling pressure and the swell percent get reduced in the case of soil-rubber mixtures containing 20% rubber by weight. Similar results were obtained later by other researchers [7]–[9] for various clays and rubber contents.

This paper presents a study on the influence of mineral and rubber admixtures on expansive properties of clay: swelling pressure \( p_s \) and free swelling coefficient \( V_p \). The swelling pressure is defined as a pressure that needs to be applied externally to prevent a submerged soil sample from swelling. The free swelling coefficient is calculated as the ratio (in \%) of the increase of soil specimen volume \( \Delta V \) and its initial volume \( V_0 \). The experiments were conducted on red Triassic clay from Patoka in Poland mixed with rubber granulate in two sizes (0.1 – 1.0 mm and 1 – 5 mm). The rubber content applied was 10\% by weight. In order to check whether the expected decrease in swelling properties results from compressive characteristics of rubber, additional specimens were prepared in which the rubber grains were replaced by sand or gravelly sand in the same proportion by weight or by volume.

2. Materials and procedures

2.1. Red Clay

The clay samples were taken from a damping site at a clay mine located in Patoka (southern Poland), belonging to a local brickyard. The soil belongs to the Tertiary deposits. The mineralogical analysis of the clay [10] revealed that it is composed of quartz, kaolinite, illite, siderite and goethite. Its characteristic red colour results from high amount of iron oxide. The organic matter content is negligible. The clay was oven dried (105°C) and ground in a ball mill to obtain a homogeneous and repetitive material for testing. The grading curve and basic physical parameters of the soil, obtained based on PKN-CEN ISO/TS 17892 [11] and PN-88/B-04481 (Proctor compaction test with normal energy) [12] are presented in Figure 1 and 0. Further in the text the soil will be called Red Clay.

| Parameter (symbol)                  | value          |
|------------------------------------|----------------|
| Particle unit weight (\( \gamma_s \)) | 27.7 kN/m\(^3\) |
| Liquid limit (\( w_L \))           | 41\% / 71\% \(^1\) |
| Plastic limit (\( w_p \))          | 22\% / 32\% \(^1\) |
| Plasticity index (\( I_p \))       | 19\% / 39\% \(^1\) |
| Mean effective particle diameter (\( d_{50} \)) | 0.0033 mm |
| Clay content (\( f_{Cl} \))        | 33\%          |
| Optimum water content (\( w_{opt} \)) | 22.5\%       |
| Maximum dry density (\( \rho_{d,max} \)) | 1.59 g/cm\(^3\) |

\(^1\)The first value refers to the clay in its natural state, the second to the clay that was dried and powdered

It has been noticed that the Red Clay in its natural state is characterized with lower Atterberg limits than after drying and grinding (see also [13]). Thus, according to the Unified Soil Classification System [14], the soil in its natural state could be classified as CL (medium plastic inorganic clay), while in the disturbed state as CH (inorganic clay of high plasticity). Depending on the method of specimen preparation also the activity (\( A = I_p/f_{Cl} \)) of the soil changes from low to normal (\( A = 0.6 \) or 1.2), which definitely influences the swelling properties of the material. For instance, Gorączko & Kumor [15] estimated that Mio-Pliocene clays from Poznań region in Poland can generate swelling pressures ranging from 5 – 600 kPa when in natural state, while 50 – 2500 kPa when dried and powdered. The
expansiveness of the Red Clay, according to Van der Merwe’s nomogram [16] could be classified as medium when in natural state and very high when disturbed.

![Figure 1. Materials grading](image)

2.2. Rubber Admixture

The rubber admixture was created in the process of shredding scrap tyres in ambient temperature into two grain sizes: powder 0.1 – 1 mm (FR) and granulate 1 – 5 mm (CR). The material contained no metal or textile cords, which were removed in the technological process. The grading curves and grading parameters of rubber powder and granulate are shown in Figure 1. The particle unit weight of the rubber was assessed as $\gamma_s = 11.5 \text{kN/m}^3$. The material was produced by ORZEŁ S.A. and ATB Truck S.A., respectively.

2.3. Mineral Admixture

Well graded sand (Sa) and gravelly sand (grSa) with the grading as similar as possible to the one of rubber powder and rubber granulate were selected as the mineral admixtures (see Figure 1). They consisted of fluvial quartz sand and gravel and so their particle unit weight was equal to $\gamma_s = 26.5 \text{kN/m}^3$.

2.4. Preparation of Specimens

Seven types of specimens were tested – their composition is presented in Table 1. Specimen RC consists of Red Clay only. Specimens RC+CR.10%, RC+FR.10%, RC+grSa.10% and RC+Sa.10% contain 10% of rubber granulate, rubber powder, gravelly sand or sand by weight, respectively. Specimens named RC+grSa.20% and RC+Sa.20% contain 21.1% by volume of gravelly sand or sand, respectively – thus the same volume of the specimen is occupied by the mineral grains as in the specimen containing 10% of rubber by weight. In terms of weight however, these specimens contain around twice as much additive as the other mixtures, which becomes visible also in their higher dry densities.

The content of each admixture by weight was calculated based on formula:

$$x = \frac{m_A}{m_A + m_{RC}} \times 100\%$$

where:

- $m_A$ – mass of the air-dry admixture (FR, CR, Sa or grSa)
- $m_{RC}$ – mass of dry Red Clay.
Table 1. Composition of specimens and their physical parameters before testing

| No. | Specimen          | Content of material in the mixture, % | Water content w | Dry density ρ_d g/cm³ |
|-----|-------------------|--------------------------------------|-----------------|----------------------|
|     |                   | By weight | By volume        |                 |                      |
|     |                   | Red Clay | Admixture       | Red Clay | Admixture |
| 1   | RC                | 100      | 0               | 100      | 0        | 21.94  | 1.58   |
| 2   | RC+CR.10%         | 90       | 10              | 78.9     | 21.1     | 19.46  | 1.53   |
| 3   | RC+FR.10%         | 90       | 10              | 78.9     | 21.1     | 19.21  | 1.51   |
| 4   | RC+grSa.10%       | 90       | 10              | 89.6     | 10.4     | 19.72  | 1.64   |
| 5   | RC+Sa.10%         | 90       | 10              | 89.6     | 10.4     | 18.94  | 1.62   |
| 6   | RC+grSa.20%       | 79.6     | 20.4            | 78.9     | 21.1     | 18.07  | 1.89   |
| 7   | RC+Sa.20%         | 79.6     | 20.4            | 78.9     | 21.1     | 17.13  | 1.85   |

To calculate the content of mineral admixture by volume the proportion between the particle unit weights of the mixed materials was considered; the volumetric content was also referred to the total volume of the mixture.

The specimens for testing were prepared by mixing the dry powdered Red Clay with distilled water to obtain the water content close to the optimum 22.5%. The material was left under cover for the next 24 hours and then ground again in a mortar to make it more homogenous in terms of water content distribution. Next the air-dry rubber or mineral admixtures were added in the proper amounts (see Figure 2). Taking into account that the rubber and sand adsorb much less water than clay, eventually the consistency of clay alone in all the mixtures was supposed to be similar. Each mixture was then compacted in the Proctor apparatus with normal energy (0.59 J/cm³: method I according to PN-88/B-04481 [12]) and a greased cutting ring 20 mm in height was next pushed into the central part of the material block by means of a hydraulic jack. The average water contents and dry densities of the specimens are presented in 0. It can be noted that addition of every 10% of rubber or mineral grains by weight reduces the water content of the mixture by about 2% when compared to clay alone. The dry density ρ_d of the clay-rubber mixtures is lower by about 3 – 4%, while for the mixtures with additional mineral grains it becomes higher by 3 – 4% or 17 – 19% depending on the fact whether there is 10% or 20% of mineral grains by weight.

Figure 2. Mixtures prepared for compaction: (from left) RC, RC+CR.10%, RC+grSa.10%, RC+grSa.20%, RC+FR.10%, RC+Sa.10%, RC+Sa.20%
2.5. Testing procedures
The free swelling coefficient \( V_p \) was estimated based on a test in a Wasiliew apparatus. Two specimens of each kind were prepared by pushing a cutting ring 58 mm in diameter and 20 mm in height into a Proctor compacted block of soil. Next, part of the material was pushed out from the ring by means of a short plunger and trimmed. Eventually the specimen’s initial height was equal to 10 mm. The ring with the soil was put in a metal container and a light porous metal plate (applying vertical stress 0.2 kPa) was placed on the specimen’s surface. After the initial decompression took place, the container was filled with water and the specimen volume increase \( \Delta V \) was measured by means of a dial gauge until there were no changes recorded within 24 hours.

The swelling pressure \( p_s \) was estimated with the use of a method suggested in PN-88/B-04 481 [12]. It required preparation of 6 specimens of each kind. Each one was introduced into a ring 50 mm in diameter and 20 mm in height, located in a classical oedometer and covered with water. Two specimens were used for initial estimation of the swelling pressure \( p_{s0} \), which was done by observing at what value of an incrementally increased vertical stress the specimen’s behaviour changes from swelling to compression. Then 4 other specimens were loaded with constant values of vertical stress: \( p_{s0} - 2\Delta \), \( p_{s0} - \Delta \), \( p_{s0} + \Delta \) or \( p_{s0} + 2\Delta \), where \( \Delta \) is an applied stress difference. Next, the observed stabilized deformation of the specimens was corrected by taking the inherent deformability of each apparatus into account (calibration with the use of a dummy metal specimen). The final value of the swelling pressure \( p_s \) was estimated as the interpolated vertical stress at which the specimen’s deformation equals zero.

3. Results and discussion
The mean increase of the vertical strain measured in Wasiliew apparatus is shown in Figure 3. The results of the oedometric tests in the form of the observed corrected vertical strain vs applied vertical stress are presented in Figure 4. The interpolated values of the swelling pressure \( p_s \) and the free swelling coefficient \( V_p \) can be found in Table 2. The \( \Delta p_s \) and \( \Delta V_p \) values show how much the estimated parameters changed when compared to the result for Red Clay.

![Figure 3. Results of free swelling tests in Wasiliew apparatus](image-url)
As expected, when unloaded and exposed to water, the Red Clay at its optimum water content and maximum dry density exhibited swelling and increased its volume by over 20%. Its swelling pressure however turned out to be relatively low (< 200 kPa) when compared to other expansive clays and may be the result of mineral composition (kaolinitic/illitic clay, with no montmorillonite). It confirms that high values of liquid limit and related index properties are less important than mineralogy when expansiveness of soil is considered, as postulated by Sridharan and Prakash [17]. Still, the swelling pressure of 120 kPa means that a light weight building or a road embankment could be easily damaged if founded on the Red Clay without stabilization.

The free swelling of the soil was reduced after adding 10% scrap tyre rubber by weight, but much more effective in this respect was rubber powder than rubber granulate (Table 2). This might be explained by two mechanisms: 1) in the clay-rubber powder mixture there are more individual rubber grains between the clay-only aggregates and thus there is less contact between the clay aggregates and more rubber-rubber and rubber-clay contacts; 2) rubber powder can adsorb more water to its surface than rubber granulate (compare with [18]) and thus less water becomes available for clay particles. It seems that the same factors are active when rubber mass gets replaced by mineral grains: free swelling of clay mixed with gravelly sand is greater than in case of the mixture with sand. This behaviour can be observed also in Figure 5, showing the development of vertical strain within the first 5 hours after application of load in oedometer (results before correction). Initially all the specimens exhibit instantaneous decrease of height but later only the Red Clay and specimens containing coarser rubber or mineral aggregates start swelling. Substitution of rubber volume with mineral components gives even better results in terms of free swelling and swelling under load (see Figure 4 and Figure 5 – the lines with full markers), however here also the finer grains are more effective. The reason why the mixtures containing 20% of mineral additives by weight exhibit less swelling may be due to their higher dry density (by almost 20%).

Figure 4. Results of oedometric tests to determine swelling pressure

![Graph showing results of oedometer tests](image-url)
Addition of 10% of scrap tyre rubber by weight decreased the swelling pressure of the Red Clay by about half. Similarly to the results of Wasiliew tests, lower $p_s$ values were obtained when rubber powder or sand were used as additives than for rubber granulate or gravelly sand. To summarize, the results of both the tests are presented together in Figure 6. The increase of vertical strain when vertical stress becomes lower can be described very well with logarithmic function, independently of the material tested (Table 2) – the correlation coefficient $R^2$ is greater than 0.98 (the only exception being RC+Sa.20% for which the $R^2$ is still relatively high).

**Figure 5.** Swelling of Red Clay and its mixtures with time at similar vertical stress

**Figure 6.** Summary of oedometric and Wasiliew tests results in semi-logarithmic stress-strain space
Table 2. Swelling pressure, free swelling coefficient and logarithmic approximation

| No. | Specimen      | Swelling pressure $p_s$ (kPa) | $\Delta p_s$ (%) | Free swelling coefficient $V_p$ (%) | $\Delta V_p$ (%) | Logarithmic approximation (Figure 6) | $R^2$  |
|-----|---------------|-------------------------------|------------------|-----------------------------------|------------------|--------------------------------------|--------|
| 1   | RC            | 120                           | 21.9             | 9.8                              | -57              | $y = -3.423\ln(x) + 16.634$          | 0.9989 |
| 2   | RC+CR.10%     | 52                            | -57              | 19.4                             | -11              | $y = -3.626\ln(x) + 13.419$          | 0.9848 |
| 3   | RC+FR.10%     | 45                            | -63              | 9.3                              | -57              | $y = -1.746\ln(x) + 6.648$          | 0.9991 |
| 4   | RC+grSa.10%   | 67                            | -44              | 16.3                             | -25              | $y = -2.916\ln(x) + 11.866$          | 0.9997 |
| 5   | RC+Sa.10%     | 34                            | -72              | 7.9                              | -64              | $y = -1.59\ln(x) + 5.3808$          | 0.9868 |
| 6   | RC+grSa.20%   | 32                            | -73              | 5.5                              | -75              | $y = -1.139\ln(x) + 3.8152$         | 0.9944 |
| 7   | RC+Sa.20%     | 36                            | -70              | 2.7                              | -88              | $y = -0.586\ln(x) + 2.0091$         | 0.8464 |

4. Conclusions

Mechanical stabilization of expansive clay by means of mixing it with other non-swelling material is an effective and cheap method to reduce its swelling ability. In this study addition of small amount (10% by weight) of scrap tyre rubber powder and rubber granulate to kaolinitic/illitic Tertiary clay decreased the soil swelling pressure by half. As far as reduction of free swelling is concerned the rubber powder turned out to be the better choice.

Mixing the Red Clay with the same amount (10% by weight) of mineral components of similar grading gave only slightly better results. In all the cases more effective was finer fraction. Replacement of rubber volume by mineral grains meant that there had to be twice as much (in terms of mass) sand or gravelly sand used. These mixtures provided the greatest decrease of free swelling but only by another 10% lower swelling pressure. This could indicate that in mechanism of the mechanical stabilization of expansive clays the most important is not the type and properties of the material that is to be added but its volume (or, in other words, the volume of swelling clay left in the mixture). It means that, from the sustainability point of view, the use of scrap tyre rubber can be an interesting solution of the problem of expansive clays as it creates an easy and effective method of soil stabilization, being at the same time a good method of utilization of this difficult common waste.

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