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Research Article

Optimization of Land Property Area for Construction Investments in the Aspect of CE - Circular Economy for Civil Engineering

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Abstract

Circular Economy (CE) is receiving increasing attention worldwide and is increasingly seen as a major policy agenda item and a testing challenge, for the construction sector. New construction investment management models in the CE trend is analyzed by new designs building constructions with new output data for constructions with the use of new building materials containing a part of the recycling materials. This research paper aims to determine the enablers of a CE for sustainable development in designing and making upgrade of engineering solutions that include current projects for the protection of our planet from the thermal effect. Construction is a resource-intensive industry where a circular economy (CE) is essential to minimize global impacts and conserve natural resources. Research into the use of retaining walls and the use of recycled materials allows for the continuous development of the field of retaining structures. The article presents a method for optimizing the development area in mountainous areas by leveling the terrain and using a slab-angular retaining wall. The main topic of the article is land leveling, designing a retaining wall and presenting the use of recycled raw materials. The publication presents patterns and methods for designing a reinforced concrete slab-angular structure in accordance with EC7, as well as the possibilities of using recycled materials.

Keywords

Leveling of Land, Retaining Wall, Circular Economy, Geotechnics, Material Recovery, Recycling, Eurocode 7, Calculations of a Slab-Angular Wall

1. Introduction

Retaining walls are structures that restrain ground pressure, thereby protecting slopes and embankments from landslides. The broad range of their applications stems from the diversity of materials used in their construction. They can be observed in the construction of roads, viaducts, bridges, slope stabilization, riverbank channelization, and the development of investment plots in mountainous areas. With technological advancements, they are also utilized to give the terrain a suitable architectural shape. This means that projects and investment implementations are often innovative [1, 2]. Retaining structures were traditionally erected in the form of retaining walls made of bricks, concrete, reinforced con-

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crete, and stones. Over time, with acquired expertise supported by numerous scientific studies, new geotechnical solutions with innovative building materials are being applied [6-9]. There is also a strive to reduce the consumption of natural materials in line with current trends in 21st-century construction, promoting Circular Economy in the construction sector, as GoGreen, NoWaste, InTech, and BeSmart [18-20].

The market value of land properties for construction investments is constantly growing and is becoming a scarce commodity in larger cities and in good locations. Geotechnical parameters of the subsoil appropriate for the designed building or structure and the new scope of utility options are crucial for estimating the investment value of building plots [5, 13]. Currently, new attributes are being generated that influence the value of real estate and are related to the construction trends of the 21st century [12, 16, 17],

Currently, an important problem is the optimization of the development area in areas with slopes and unevenness. When analyzing this issue, the leveling of the plot area is examined for the assumed level surface, which can be almost entirely developed for investment purposes after appropriate strengthening and protection of the resulting ground faults using the retaining wall discussed in this article [3, 4]. The use of these structures allows for wider possibilities of using the area designated in local development plans for construction investments [14, 15].

1.1. Objective and Scope

The analyzes and research described in the article aim to present the optimal approach to the development of plots for investment in areas with significant slopes and unevenness. The publication presents information on the analyzed types of retaining walls, current construction solutions, innovative implementation methods and new trends in the use of the presented solution. The paper analyzes the calculation methods for the slab-angular retaining wall according to EC7 [10], in the aspect of current legal and methodological guidelines.

1.2. Description of the Test Method

For the surface optimization analysis, a scheme with preliminary assumptions consistent with Figure 1 was adopted. An example of the analyzes carried out in this publication is a plot located in a mountainous area with a slope of 13%. It all depends not only on the needs and requirements we want to achieve, but also on the type of land, water conditions and the possibility of development by the competent authority. By leveling the terrain on the required surface, we can obtain a uniform height or slope. If the plot has one surface, the complexity of subsequent construction works can be reduced, among others: by setting the depth of the foundations on one level, building a sidewalk or terrace on one level around the facility.

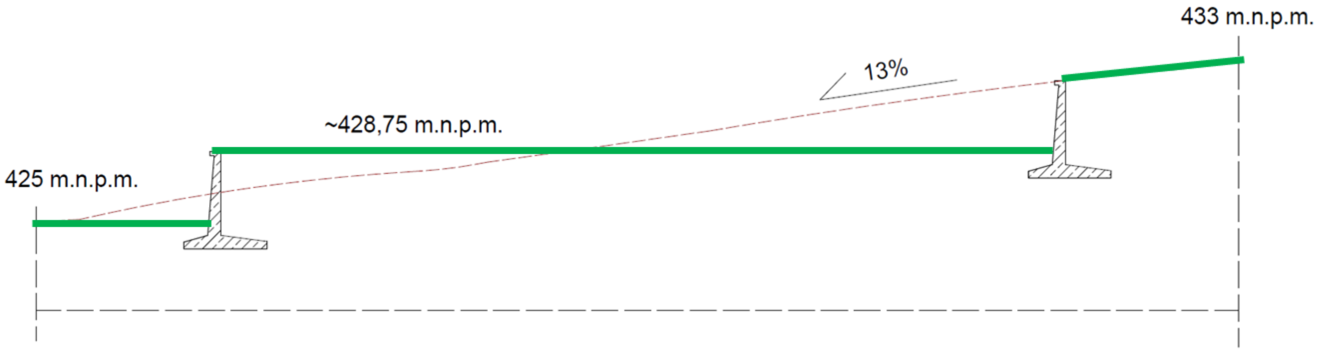

Figure 1. *Scheme of land leveling for surface optimization. Own study.*

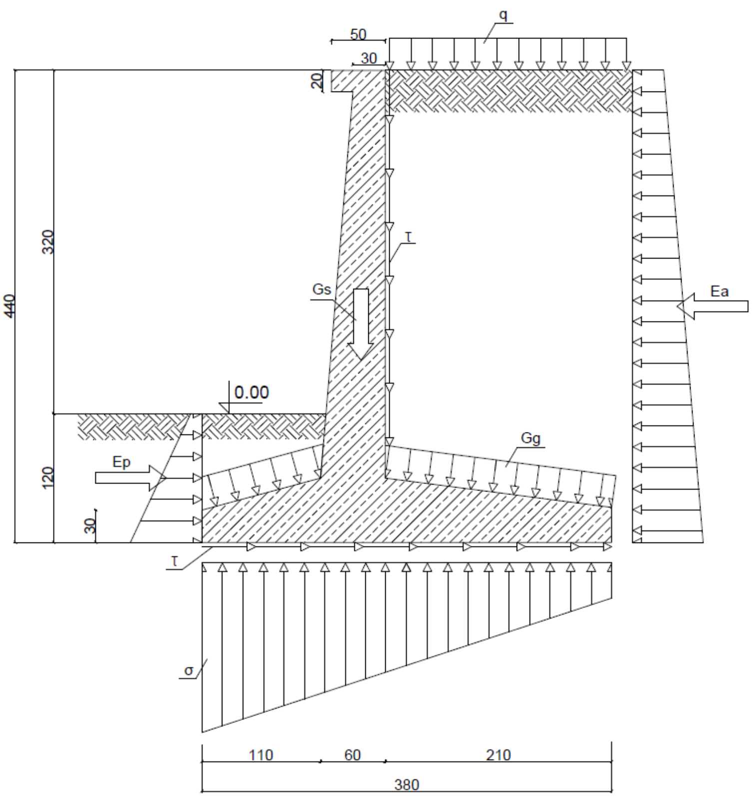

Figure 2. *Load scheme acting on the structure along with its dimensions. Own study.*

Forces analyzed acting on the structure:

Gs - own weight of the wall

Gg - resting load on the wall elements

Ep - passive earth pressure

Ea - active earth pressure

q - resting load

τ - friction between the soil and the structure

σ - interaction of the soil below the foundation

When performing calculations, partial coefficients of geotechnical parameters are used, checking individual states, bearing capacity, resistance and ground resistance, in accordance with EC7 Annex A.

The formulas necessary to perform design calculations are: [10]

a. Boundary soil pressure coefficient (K_{a1}) and passive earth pressure (K_{p1}) for a specific type of soil:

$$K_{a1} = (\tan\left(45° - \frac{\varphi_1}{2}\right))^2 \text{ and } K_{p1} = (\tan\left(45° + \frac{\varphi_1}{2}\right))^2$$

where: φ_1 - internal friction angle

b. Characteristic value soil pressure:

$$e_{a0} = q_k * K_{a1}$$

$$e_{a1} = \gamma_1 * z_1 * K_{a1} + q_k * K_{a1}$$

where: q_k - uniformly distributed load

γ_1 - volumetric weight of soil

c. Characteristic resultant soil pressure:

$$E_{a1} = 4 * e_{a0}$$

$$E_{a2} = 0.5 * 4 * (e_{a1} - e_{a0})$$

d. Calculated value soil pressure:

$$e_{a0.0} = \gamma_Q * q_k * K_{a1}$$

$$e_{a1.1} = \gamma_G * \gamma_1 * z_1 * K_{a1} + \gamma_Q * q_k * K_{a1}$$

where: γ_G - partial coefficient for permanent loads

γ_Q - partial coefficient for variable loads

e. Resultant of the design soil pressure:

$E_{a1.1}$= 4*$e_{a0.0}$

$E_{a2.2}$= 0.5*4*($e_{a1.1}$− $e_{a0.0}$)

f. For the adopted dimensions of the retaining wall, the so-called geometric volume of individual solids as V = H*a*b, and then the load components from the wall, soil and backfill are calculated from the formulas:

$$G_k = V * \gamma * \frac{1}{m} \text{ and } G_d = \gamma_G * G_k.$$

where: V is the geometric volume of the solid,

G_k is the characteristic permanent load,

G_d is the volumetric weight of the ground

g. The individual components should be summed:

$$\sum G_{i.k} \text{ and } \sum G_{i.d}$$

where: $\sum G_{i.k}$ – the total vertical load,

$\sum G_{i.d}$ – the total calculated vertical load.

h. Checking the limit states of the soil is based on calculations made based on the above formulas. The load-bearing capacity of the substrate is also checked:

$$V_d \leq \frac{R_d}{\gamma_{R.v}},\ V_d = \sum G_{i.d}$$

where: $\gamma_{R.v}$ – partial load-bearing coefficient,

V_d – design value of the vertical force in the foundation level,

R_d – calculation value of ground resistance.

i. The next stage is to determine the characteristic values relative to the center of the foundation base, calculate the pressure from the formulas e and determine the sum of moments from all calculated forces from the geometric center M from the formula:

$$M_{0.k} = G_{1.k} * a_{1.a} + G_{2.k} * a_{2.a} + G_{4.k} * a_{4.a} + (E_{a1.1} * e_{a1.1} * m + (E_{a2.2} * e_{a2.2} * m - G_{5.k} * a_{5.a} - G_{6.k} * a_{6.a.}$$

where: $a_{n.a}$ – the distance relative to the center of the foundation base.

j. $M_{0.k}$ compare to the calculated amount of eccentricity relative to the center of the wall base:

$$e_B = \frac{M_{0.k}}{\sum G_{i.k}} < \frac{B}{6}$$

A positively fulfilled condition guarantees that detachment will not occur

k. After meeting the above condition, you can proceed to calculate the effective dimensions of the slab and the coefficients of inclination of the base, shape, and resultant inclination:

$$i_q = (1 - \frac{E_{a1.1} * m + E_{a2.2} * m}{\Sigma G_{i.d}})^2$$

$$i_\gamma = (1 - \frac{E_{a1.1} * m + E_{a2.2} * m}{\Sigma G_{i.d}})^{2+1}$$

$$N_q = e^{\pi * \tan(\varphi_1)} * (\tan(45° + \frac{\varphi_1}{2})^2)$$

$$N_\gamma = 2 * (N_q\text{-}1) * \tan(\varphi_1)$$

where: i_q, i_γ – coefficients of the resultant slope

N_q, N_γ – load-bearing coefficients

l. Unit computational load of the substrate due to characteristic loads:

$$q_{k.\frac{max}{min}} = \frac{\sum G_{i.k}}{1 * B} \pm \frac{6M_{0.k}}{1 * B^2} \text{ and } \frac{q_{d.max}}{q_{d.min}}$$

m. Calculation condition for the bearing capacity of the substrate:

$$R_d = B_{prim} * L_{prim}(Nq * q_{prim} * s_q * i_q * b_q + \frac{N_\gamma * \gamma_1}{2} * B_{Prim} * s_\gamma * i_\gamma * b_\gamma)$$

$$\frac{V_d}{\frac{R_d * 1}{\gamma_{R.v}}} < 1{,}0$$

where: B_{prim}, L_{prim} – are the effective dimensions of the foundation slab,

b_q, b_γ – are the inclination coefficients of the foundation base,

s_q, s_γ – are the shape coefficients,

q_{prim} – is the effective stress.

n. If the above condition is met, further calculations for stability against sliding can be carried out.

$$\sum E_a = E_{a1.1} + E_{a2.2}$$

$$H_d = \sum E_a * 1m$$

$$V_k = \sum G_{i.k} - G_{4.k}$$

$$R_k = V_k * tan(\varphi_1)$$

$$R_d = \frac{R_k}{\gamma_{R.h}}$$

$$R_d \geq H_d$$

where: $\gamma_{R.h}$ – coefficient of partial resistance to sliding

H_d – is the calculated value of the vertical force acting at the foundation base, $\sum E_a$ – is the sum of calculated resultant pressures.

Fulfilling the above condition ensures safety against sliding.

o. Checking state the limit of equilibrium is performed using formulas from points a) to i), at point i) instead of $M_{0.k}$ is calculated $M_{0.d} = E_{aa1.1} * e_{a1.1} * 1.0m + E_{aa2.2} * e_{a2.2} * 1.0m$ and calculating the sum $M_{u.d} = G_{1.ad} * a_{1.aa} + G_{2.ad} * a_{2.aa} + G_{3.ad} * a_{3.aa} + G_{5.ad} * a_{5.aa} + G_{6.ad} * a_{5.aa}$.

To positively satisfy the condition, the moment holding the wall ($M_{u.d}$) must be greater than the moment trying to rotate the wall ($M_{0.d}$).

$$M_{u.d} > M_{0.d}$$

2. Results of Calculations and Analyzes Performed to Optimize the Retaining Wall

C20/25 class concrete with recycled aggregate elements and

RB400W steel with an admixture of 13-20% Riesling steel with parameters higher than the design ones were used. For the adopted scheme, calculations from points b) and d) were made in order to calculate the soil pressure values for the cross-sections: in the level of the top of the slab, in the fastening cross-section and in the middle the height of the vertical slab. Calculations were made for the cross sections marked in Figure 3.

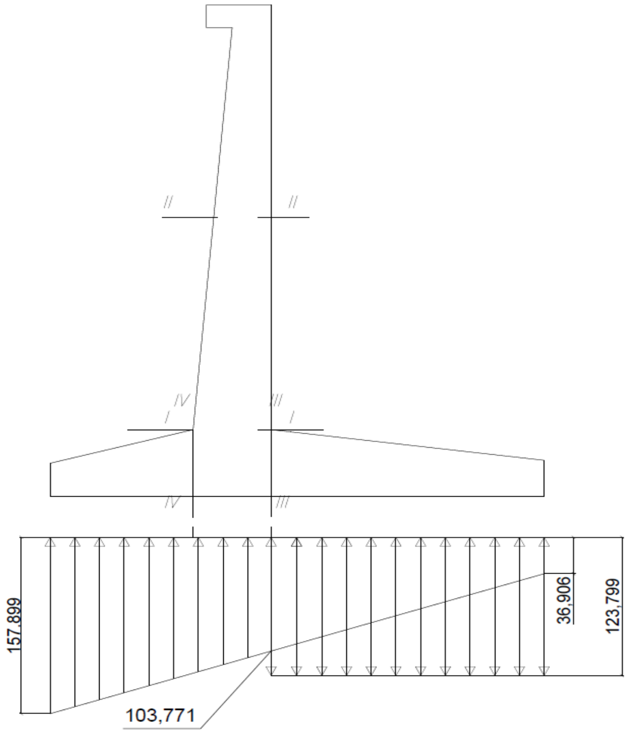

Figure 3. *Diagram of cross-sections of the structure with the distribution of forces under the base. Own study.*

for cross-sections I-I and II-II, the bending moment is calculated:

$$M_{Sd1} = e_{a0.0} * z_{1.1} * z_{2.2} + 0.5 * (e_{a1.1} - e_{a0.0}) * z_{1.1} * \frac{1}{3} * z_{1.1}$$

$$M_{Sd2} = e_{a0.0} * z_{2.2} * 0.5 * z_{2.2} + 0.5 * (e_{a2.2} - e_{a0.0}) * z_{2.2} * \frac{1}{3} * z_{2.2}$$

where: z - cross-section intersection distance

The optimal useful cross-section height for a given task was estimated:

$d = h_p - c_p - \Delta h - \frac{\phi_p}{2}$ with dimensions of 533mm

where: h_{p1} – is the thickness of the plate,

c_p – is the cover of the reinforcement bars,

Δh – is the permissible deviation of the cover thickness,

ϕ_p – is the diameter of the main reinforcement bars in the plate.

The required amount of reinforcement was calculated using the formulas:

$$\mu_{eff} = \frac{M_{Sd}*L}{b_p*d^2*\eta*f_{cd}}$$

$$\varsigma_{eff} = 1 - \sqrt{1 - 2\mu_{eff}}$$

$$\varsigma_{eff} = 1 - \frac{\varsigma_{eff}}{2} = 1$$

$$A_{s1.min} = 0.0013 * b_p * d \le A_{s1.req} = \frac{M_{Sd1}*L}{\varsigma_{eff}*d*f_{yd}}$$

A combination of at least 13% and at most 22% recycled reinforcement was used, this combination meets the conditions for cross-sections I-I, II-II.

where: $A_{s1.req}$ – required amount of reinforcement,

b_p – width of the calculation cross-section of the slab,

f_{yd} – design yield strength of reinforcing steel.

For the horizontal slab in section III-III, the design load acting from above = $(a_a * \gamma_{Bet} + H_a * \gamma_1) * \gamma_{G+}\gamma_Q * q_k$. The overhang of the longer support of the foundation slab $q_{d.kIII} = q_{d.min} + \frac{(q_{d.max}-q_{d.min})*d_{III}}{B}$ and the maximum design bending moment $M_{SdIII} = \frac{0.5*[(q_{dIII}-q_{d.min})+(q_{dIII}-q_{d.kIII})]*d_{III}^2}{2}$. The cross-section of the reinforcement placed on top in the horizontal slab is calculated from the formulas q).

where: d_{III} – overhang of the longer support of the foundation slab

γ_{Bet} – volumetric weight of concrete determining the loads that act on the foundation slab analyzed in the task before backfilling: the weight components of the vertical and horizontal slab from point f) and the arms of the forces $G_{n,d}$ for $r_{1i2} = a_{0.aa} - a_{n.aa}$, sum of moments relative to the center of the substrate $\sum M_{0.d} = G_{1.d} * r_1 + G_{2.d} * r_2$. You should also determine the design unit load of the substrate before covering the wall in accordance with point l) and determine the design load taking into account the maximum bending moment and the required reinforcement q).

In the last stage of the computational carried out analysis, the values of the shorter support of the foundation slab with a cross-section of IV-IV, according to the formulas for the horizontal slab and the required reinforcement q).

3. Results of the Conducted Calculations

With reference to the formulas described in the article, calculations were performed for the examined task. Calculations for a retaining wall with a slab-angular structure were made for a designed total height of 4.4 m, embankment height of 3.2 m, and a backfill load of q_k =11 kPa. The structure was planted at a depth of 1.2 m, in accordance with the frost zone applicable in a given area in Poland. Based on the conducted ground tests, the property was identified as geotechnical category I, i.e. CSa soil with a degree of compaction, Id = 0.55, bulk density $\rho_1 = 1.86\frac{t}{m^3}$, cohesion c_1=0 kPa and internal friction angle $\varphi_1 = 33.34°$.

All limit states checked:

a. Bearing capacity of the subsoil:

$$V_d = \sum G_{i.d} = 370.13\frac{kN}{m}$$

$$R_d = 2007.38kN$$

$$\frac{V_d}{\frac{R_d*1}{\gamma_{R.v}}} = \frac{370.13kN}{2007.38\frac{kN*1}{1.4}} = 0.26 < 1{,}0$$

Condition fulfilled

b. Checking the stability against displacement:

$$H_d = 82.18\frac{kN}{m}$$

$$R_d = 157.96\frac{kN}{m}$$

$$R_d = 157.96\ \frac{kN}{m} \geq H_d = 82.18\ \frac{kN}{m}$$

Condition fulfilled

c. Checking the equilibrium limit state:

$$M_{0.d} = 134.1kNm$$

$$M_{u.d} = 510.55kNm$$

$$M_{u.d} = 510.55kNm > M_{0.d} = 134.1kNm$$

Condition fulfilled

For the vertical slab, the bending moments and the amount of required reinforcement for each section were calculated:

Cross-section I-I: $M_{Sd1} =$ 100.098 kNm

$$A_{s1.req} = 5.467cm^2$$

$$A_{s1.min} = 6.93cm^2$$

$$A_{s1.prov} = 6.93cm^2$$

$$A_{s1.prov} = 6.93\ cm^2 \geq A_{s1.min} = 6.93\ cm^2$$

Condition fulfilled

Cross-section II-II: $M_{Sd2} = 16.841$kNm

$$A_{s2.req} = 1.304cm^2$$

$$A_{s2.min} = 4.85cm^2$$

$$A_{s2.prov} = 4.85cm^2$$

$$A_{s2.prov} = 4.85\ cm^2 \geq A_{s2.min} = 4.85\ cm^2$$

Condition fulfilled

Horizontal plate

Cross-section III-III:

$$q_{dIII} = 123.799\frac{kN}{m^2}$$

$$q_{d.max} = 157.899\ \frac{kN}{m^2}$$

$$q_{d.min} = 36.906\ \frac{kN}{m^2}$$

$$q_{d.kIII} = 103.771\frac{kN}{m^2}$$

and the required reinforcement cross-section:

$$A_{s3.req} = 6.455cm^2$$

$$A_{s3.min} = 6.929cm^2$$

$$A_{s3.prov} = 6.929cm^2$$

$$A_{s3.prov} = 6.929\ cm^2 \geq A_{s3.min} = 6.929\ cm^2$$

Condition fulfilled

Calculation of the reinforcement cross-section (placed at the bottom) in the horizontal slab:

$$A_{s3.req} = 8.098cm^2$$

$$A_{s3.min} = 6.929cm^2$$

$$A_{s3.prov} = 8.098cm^2$$

$$A_{s3.prov} = 8.098\ cm^2 \geq A_{s3.min} = 6.929\ cm^2$$

Condition fulfilled

Cross-section IV-IV:

Shorter foundation slab bracket:

$$A_{s4.req} = 1.087cm^2$$

$$A_{s4.min} = 6.929cm^2$$

$$A_{s4.prov} = 6.929cm^2$$

$$A_{s4.prov} = 6.929\ cm^2 \geq A_{s4.min} = 6.929\ cm^2$$

Condition fulfilled

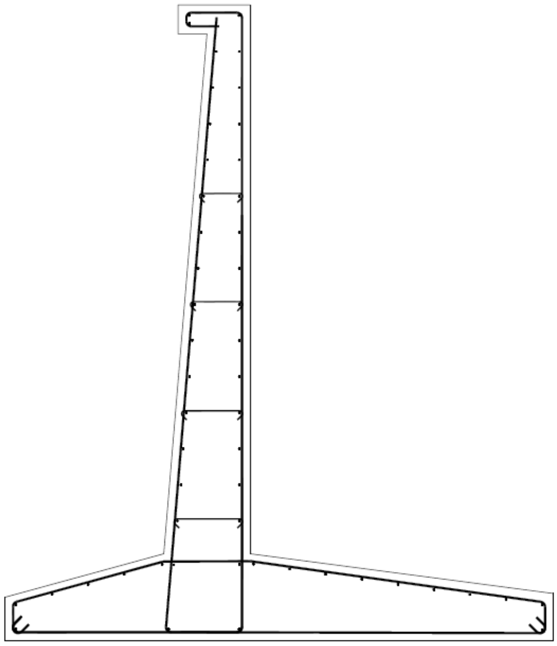

Figure 4. Reinforcement arrangement of the slab-angular retaining wall. Own study.

4. Discussion

To implement the designed structure, it was proposed to use an alternative material for C20/25, i.e. recycled aggregate. Construction recycling involves the recovery of materials and primary raw materials through the use of patented technology. Recycled materials are only slightly inferior to primary materials and raw materials, and they fit perfectly into the new trend in construction, which is the Circular Economy in civil engineering. The detailed design preferred the use of concrete rubble according to the method developed by the Białystok University of Technology, which consists of several stages:

1) In the first stage, the concrete rubble is crushed into smaller fractions, with a maximum diameter of 40 mm, and one of the crushing methods is a jaw crusher.
2) The rubble is then placed in a heat treatment oven. The entire process takes about 1 hour at 650 ℃. Temperature weakens the connection of aggregate grains with cement paste in concrete. This is because calcium hydroxide usually accumulates in this place, which decomposes into lime and water when the temperature is reached.
3) The next step is to place the burnt rubble into a rotating drum, where it is mechanically processed. Friction between the grains and the inner surface of the drum removes the cement mortar from the surface of the aggregate grains.
4) The material is then sieved into the desired fractions, including high-quality coarse aggregate and fine concrete aggregate.
5) It is also recommended to grind fractions below 4 mm into finer particles. Thanks to this treatment, it is a valuable addition to concrete.

The mentioned recycled material was proposed for the presented project as an addition to concrete and a partial replacement for cement. As mentioned earlier, the given structure reinforcement also comes from recycling, and its values range from 13 to 22% in different cross-sections [4-7, 21-23].

Moreover, the designed backfill is also to be made of recycled material, with physical and mechanical parameters comparable to the assumed CSa, Id = 0.55. It is recommended that the material be anthropogenic material, originating from mining and metallurgical waste zones, with appropriate physical and strength parameters. In Poland, the use of this type of solutions as an alternative material to native and embankment soils, often constituting an addition, is becoming more and more popular. Thanks to such design assumptions, investment costs are reduced, waste is removed from mining dumps and the reclamation of urban areas is promoted [11-15, 19].

The parameters of anthropogenic soils may vary, therefore, before using them, it is recommended to prepare an individual project based on calculations and research. It is worth adding that this type of soil is used for leveling the ground, stabilizing foundations, substructures and as filling for retaining structures such as gabions [16-18].

5. Conclusion

The presented project, together with assumptions and calculations, is consistent with the main goal, which is to level the area for a construction investment in order to optimize the area. The designed structure meets EC conditions and is consistent with the applicable legal and methodological bases and the Circle Economy trend for the construction industry. By using the method of leveling sloping areas with retaining walls, you can gain space for wider use of investment areas. The remaining mine waste can be successfully used in construction, saving natural resources and thus limiting their extraction, reducing the number of heaps, which has a positive impact on the environment and is an economic solution. The reuse of waste presented in the article has a positive impact on the environment and saves natural resources. It is also an economic solution that helps reduce project implementation costs, which is why it is becoming more and more popular. By using the mentioned construction materials, the project can be considered environmentally friendly from the point of view of a circular economy for civil engineering.

This paper informs that everybody know that a range of capabilities, models, practices, policies and incentives are required as we transition to a building materials circular economy by 2050. Now there are multiple aspects of reuse and waste in material designers for new construction investments that should be use in new construction and executive projects. The researched and analyzed in the development of the design and executive development of construction investments generates many engineering and economic questions regarding the life cycle of such investments and investment costs in accordance with EC trends. An important question for implemented scientific and technical and design tasks is the answer to the basic question: what supply-side drivers and dynamics could accelerate the contribution of building materials to decarbonising the new CE civil engineering system? Current construction projects and investments start verifying CE assumptions in the implemented building projects in Poland. In a few maybe a dozen or so years we will get a response whether the assumed physical, wearing and environmental features have come true.

Abbreviations

EC: European Standard for Design
EC7: Eurocode 7 European Standard for Geotechnical Design
kN: Force
kg: Mass
kNm: Moment
kg/m^3: Mass Density
kN/m^3: Weight Density
kPa: Stress, Pressure, Strength and Stiffness
Φ': Angle of Shearing Resistance in Terms of Effective Stress
Φ'_d: Design Value of *Φ*
c: Cohesion Intercept
c': Cohesion Intercept in Terms of Effective Stress
E_d: Design Value of the Effect of Actions
G: Design Value of the Destabilizing Permanent Actions
q: Characteristic Value of Unit Resistance
R_d: Design Value of the Resistance to an Action
V: Vertical Load, or Component of the Total Sction Acating Normal to the Foundation Base
V_d: Design Value of V
σ (z): Stress Normal to a Wall at Depth z
τ (z): Stress Tangential to a Wall at Depth z
CSa: Coarse Sand – Symbol by PN-EN ISO 14688-1
I_d: Degree of Compaction for Subsoil

Conflicts of Interest

The authors declare no conflicts of interest.

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