Assessing Multiple Engineering Tasks Via Escape Room Game

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Abstract: - Education as a concept includes every effort to train and develop people and their skills by applying the appropriate tools. One type of education is the formal, which includes a logically built and organized curriculum that is under the jurisdiction of state mechanisms. However, there is also a non-formal education which, unlike the formal one, refers to all organized educational programs that take place outside the institutional framework of formal education and are usually voluntary and short in duration. It is mainly addressed to adults and does not have to provide a document certifying education in this field. In this context, the present work, adopting the research methodology based on design, aims to develop and formulate a mobile augmented reality game in the form of an escape room/s targeting train engineers. The purpose of this paper is the evaluation of advanced students, through a series of high level and content of polytechnic questions, in the context of group collaborations that are formed during the coexistence of students in escape rooms, where an augmented reality is incorporated. Finally, the aim of this work is the implementation and evaluation of one or more thematic escape rooms regarding the mobilization, satisfaction and involvement of polytechnic students in puzzles and problems that require significant engineering knowledge.

Key-Words: mechanics of materials, civil engineering and informatics, escape-room-game, educational engineering training, soil mechanics, reinforced concrete, fluid mechanics, databases.

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1 Introduction

"Escape Rooms" is the name of an interesting trend of modern times that has flourished in the last decade in many countries around the world. These are puzzle and composition games, in which participants are asked to work together and solve problems using the information that exists in the room/s to unlock the door and escape. These types of games belong to the broader category of escape games, but differ from the rest due to the live interaction they provide with the environment. The main benefits of these games are the promotion of collaboration, the development of problem-solving strategies, critical thinking, imagination and creativity, elements that are necessary for the professional activity of an engineer. Escape rooms require teamwork, communication, initiative, as well as critical thinking and attention to detail along with an ability to apply a wide range of knowledge and effective methods under the pressure of time.

Escape rooms, as a group action and adventure game with the main goal of escaping from a room, appeared a few years ago in Japan and quickly spread to the rest of the world. Their team spirit and opportunities for knowledge building, skills development, and emotional engagement are the reasons why the research community has turned in a new direction. We are talking about exploring the opportunities that escape rooms can provide as teaching and learning environments. Through the escape rooms, the student acquires the feeling of cooperation, teamwork, strategy, skill, problem solving, and knowledge acquisition, [1].

In conclusion, the process of solving puzzles in an escape room is essentially a collaborative problem-solving process in which players exchange information, access different elements at the same time, use a variety of skills and knowledge due to the variety of puzzles found in the room, [2]. Escape rooms display characteristics that enhance learning and teaching through problem-solving. The present work aims at the design, development and evaluation of an educational process that belongs to the category of escape games, [3], [4]. To create such an educational tool, it is necessary to investigate the pre-existing literature, [5], [6], both to highlight the benefits of using the escape rooms in the educational process and present the results of relevant research. Initially, it turned out that regardless of educational content and age, escape rooms in education were an auxiliary tool for understanding concepts difficult to follow traditionally, while encouraging users to show improved attitude, mood and activity. Particularly impressive is the fact that the majority of research that has been carried out is directed towards the Higher Education, utilizing both Information and Communication Technologies, in order to achieve the development of a suitable escape training room. In the majority of researches that are known so far, it became clear that through the escape training rooms the students developed important cooperation skills along with problem solving strategies, necessary for their later professional career.

2 Literature Review

In the present study, the usefulness of escape rooms in the education of engineering graduates is presented and discussed. Initially, various researchers [1], [2], [3], attempt to describe the way that escape rooms operate along with their interactivity as mobile games in the classroom and generally in education, however without reference to engineering education. Other scholars [4] are closer to the assessment of engineers but refer only to first-year students and not to seniors while developing the interactivity within the space of one room. We use six rooms in our submitted article and clearly emphasize its originality. A very interesting article by another researcher [5] is related to the educational function, but not to that of escape rooms. Another article [6] approaches undergraduate and graduate students of the civil engineering department of technological education through interesting questionnaires, however not via interactive procedures that appear in escape rooms.

The book chosen for the development of the theoretical background of Soil Mechanics (room 1) and especially for the methods of buttress and design of earthy soils, as well as several articles [7], [8], [9], [10], [11], [12], [13], [14], [15], was instrumental. The works of other researchers [16] take into consideration the effect that spatial variability of the soil properties has on the seismic behavior of the soil slopes, knowledge which is necessary for the way of their buttressing and were also a source for the puzzles. The topic given for solving to the final-year students is completely covered by the above literature which, however, has no references to interactive educational procedures nor to escape rooms. Certainly, this note, along with a number of six escape rooms presented below leads to the indisputable conclusion that the present work is completely original.

The books of classical mechanics and applied statics, [17] [18], [19], [20], have significantly helped to develop the theoretical background of Statics. The important publications of [21], [22], [23], [24], [25], [26], [27], have also contributed to interactive processes as ways of learning by final year students for the theoretical background of Strength of materials.

It should be emphasized that books and publications [28], [29], [30], as well as other contributions [31], [32] provided interesting scientific ideas to formulate the questions-answers of the Hydraulics room (room 4) and for this reason, they are included in the bibliography. However, they do not refer to escape rooms in education, which is the aim of this article.

Furthermore, the book and publications [33], [34], [35] present important facts about the knowledge, development, and research of reinforced concrete but without references to interactive educational processes presented in room 5. Another book and several publications [36], [37], [38] introduce students to the world and evolution of IT and have significantly helped to develop the theoretical background of computer science (room 6), but without references to interactive processes as ways of learning for engineering graduates. Finally, it should be emphasized that this work is the only one that presents ways of learning and training graduate engineers using six escape rooms, with the parallel development of important collaboration skills as well as problem-solving strategies, necessary for their future professional careers.

3 Methodology

3.1 Active learning – Benefits of escape training rooms

Compared to the traditional lecture, the "active learning" of an escape room will not only raise students' interest but may offer a way out for further occupation beyond the escape game. Many academics follow this way of teaching, modifying their teaching style in order to improve communication with their students, but also to motivate them to participate in the classroom's activities. A professor of game design and development at the University of Canada Wilfrid Laurier [1], puts it in his journal: "The meaning of substantial gamification is not to provide external rewards, but to help participants find a deeper connection to the underlying theme. The main bet of educators is to instill a deep passion in their students; otherwise, they would feel that they have failed as teachers.

Escape training rooms can be extremely effective in universities because of their ability to adapt to any subject. Some academics have noticed that students' desire to learn has increased significantly, allowing many of them to thrive in this natural problem-solving environment, even those who do not normally interact in the classroom [39].

From the beginning, the escape rooms manage to quickly charm the participants and make them work with their teammates to achieve their overall goal. In the classroom environment, students are more likely to retain the object material through active learning and apply what they have learned in different situations, rather than memorizing events. Some teachers hope that these lessons taught in a fun, attractive environment will overcome the classroom. Critical thinking is a means of being able to think creatively and come to different conclusions when presented with the same (or similar) problems. The benefit of an educational getaway and its highly adaptable nature, regardless of the environment, is therefore proven.

3.2 Form of escape room and troubleshooting routes

The escape rooms can be defined as educational when they include the materials of the lesson in their puzzle in such a way that the students can use in an elaborate and creative way the data given to them and solve the puzzle. Usually, an escape room is considered to be well-structured when the existing puzzles have the ability to be connected to each other, thus increasing the difficulty of solving it while offering a series of challenges to the players. Since the escape areas are inextricably linked to the teamwork, the puzzles must be designed in a way to ensure the active participation of each player individually. In fact, there are many studies that report their positive influence in later stages of education, covering therefore successfully a wide range of scientific disciplines.

Initially the group of students to be put to the test enters the reception area and after registration, through the inner door (Fig. 1) is guided in the first room.

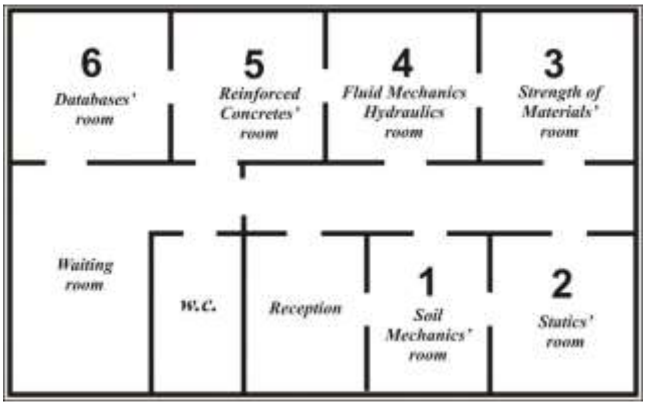


Fig. 1: Plan of Escape Room

Following is the process of solving the 1st complex puzzle. After removing the difficulties presented and the correct answers, the team proceeds to the 2nd room. The entrance is achieved by unlocking the inner door between the first two rooms. It should be noted that in each room there is an emergency exit that facilitates the escape in case a member of the team is not able to continue. The process proceeds for the total of six rooms but the puzzles and questions concerning engineering issues are considered to be of equivalent difficulty in each escape room. After solving the puzzles of the 6th room, the players are led to the terminal exit.

4 Description of Puzzles – Escape

4.1 Soil Mechanics room

Initially, the group of students - players is led by the teacher–game master in the 1st room where there is the appropriate logistics infrastructure. The group is invited to start the game, without any information available in advance. Several possible applications to be used by the students are provided by the computer on the room desk. To begin with, the students are provided with a manual describing the steps to be followed to solve the riddles and move on to the next room. This manual informs them that they must first select one of the two photos that are placed on a bench in the corner of the room. Relatively easily, students can distinguish in the portraits the famous French engineer Charles Augustin Coulomb (Fig. 2) as well as the Austrian engineer Karl Terzaghi (Fig. 3) who went down in history as the "Father of Soil Engineering".

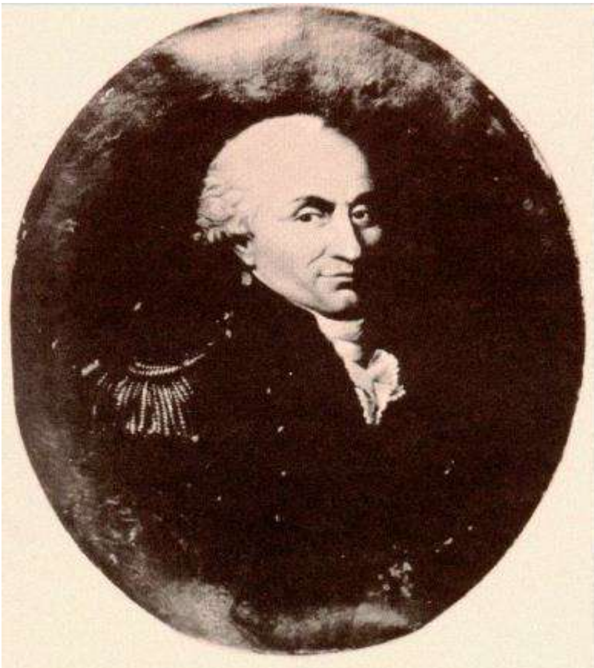


Fig. 2: Charles Augustin Coulomb (1736–1806)

Fig. 3: Karl von Terzaghi (1883−1963)

When they browse the 1st portrait an arrow shows them in the back the 2nd portrait and when they turn the 2nd over, an arrow shows them the only drawer of this room. Of course, they open the drawer, in which they find a page where the loading of a pile board with the required soil mechanical characteristics is illustrated (Fig.4). They are asked to calculate the diagrams of the thrusts that develop at the height of the structure that supports the ground, [16], [17], [19], [20].

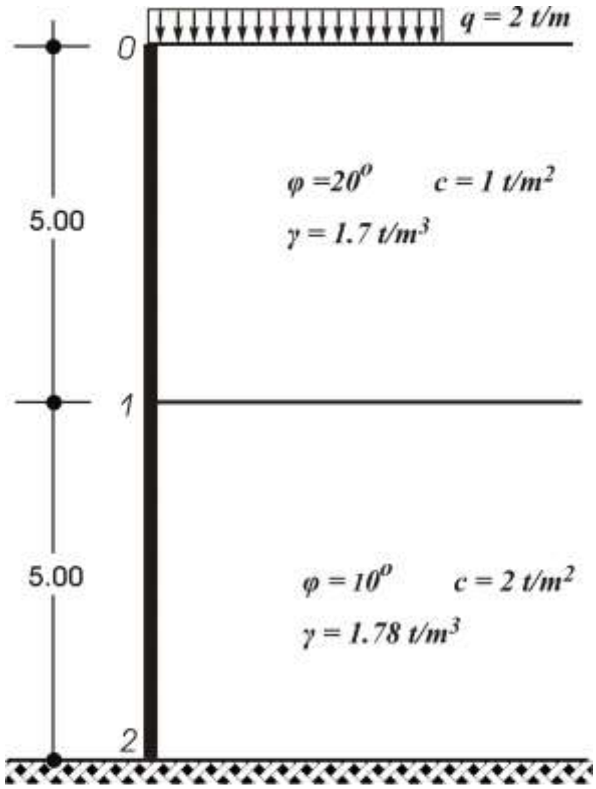


Fig. 4: Loading of a pile board

The next page says: "Show the correct solution to the computer". The students try each and every one of them to solve the issue of soil-mechanics and when they finish their thinking, they formulate it in a notebook that they had with them before the start of the game. When they scan the solution (Fig. 5) on the multifunction machine next to the computer, the monitor shows: "Correct answer, you can move on to the next room". At the same time, the inner door unlocks and the students pass to the next room, [26], [27].

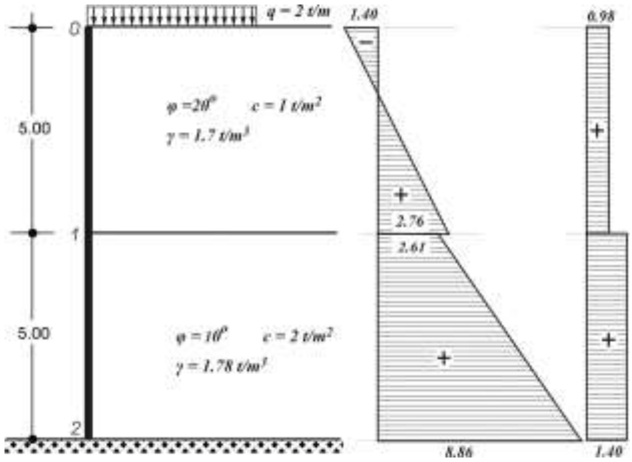


Fig. 5: Solution of the pile board

4.2 Statics room

Here the students will need to use basic knowledge of Statics combined with Algebra. On the table of the room there is a piece of paper where a statically determinate beam is depicted, shown in Figure 6.

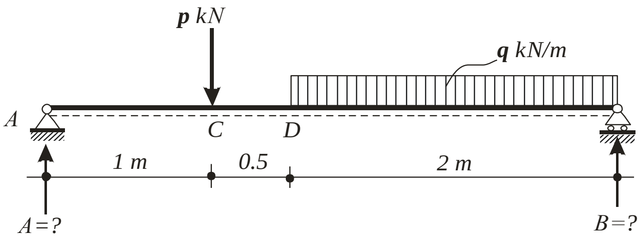


Fig. 6: Simply supported beam

Caution! To calculate the reactions correctly you should use the correct values for the parameters p and q, i.e.:

p is 1/5 of the positive root of equation $x^2 - 5x - 24 = 0$ and

q is 1/5 of the number of members that exist in a statically determinate simply supported truss with 7 joints.

Then, after locating the point where the shear force is zero, you have to calculate the maximum bending moment, which you will use as a key code to enter the next room! The correct answers that lead to the key value are shown in Figure 7, [21], [27].

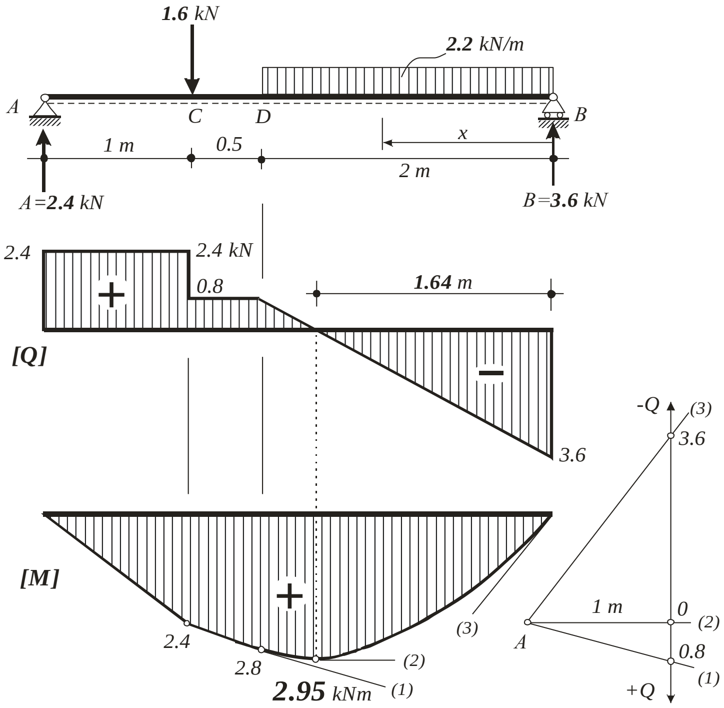


Fig. 7: Shear forces and bending moments diagrams

4.3 Strength of materials room

Making use of the maximum values M_{max} and Q_{max} that was found for bending moment and shear force in the previous room, the students here have now to determine the dimensions of the beam's cross-section, applying the corresponding knowledge of the Mechanics of materials, [23], [24], [25], [26].

It is assumed that the material is steel, the cross-section is rectangle (Fig. 8) and the plane of bending contains the section's vertical axis of symmetry. Given are also the allowable stresses for the steel:

- ✓ in bending $\sigma_{allow} = 160\ MPa$,
- ✓ in shear $\tau_{allow} = 90\ MPa$.

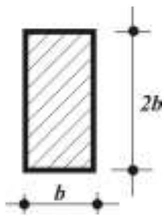


Fig. 8: Rectangular cross-section

The strength of the beam will be checked both in bending and shear.

The number **b** of the cross-sectional **base**, expressing the **minimum integer in mm**, should be the key code to enter the next room.

The necessary cross-section's moment of resistance, W_{nec}, due to the height / base relation, is

$$W_{nec} = \frac{bh^2}{6} = \frac{2b^3}{3}.$$

Therefore, the relation which expresses the bending strength control,

$$\sigma_{max} = \frac{M_{max}}{W_{nec}} \leq \sigma_{allow},$$

becomes

$$\frac{2b^3}{3} \geq \frac{M_{max}}{\sigma_{allow}} \qquad \text{or}$$

$$b \geq \sqrt[3]{\frac{3 \cdot 2.95 \cdot 1000\, Nm}{2 \cdot 140 \cdot 10^6 \frac{N}{m^2}}} = 0.0302\, m.$$

The corresponding shear-strength stress-control,

$$\tau_{max} = \frac{1.5 \cdot Q_{max}}{A_{nec}} \leq \tau_{allow},$$

since $A_{nec} = 2b^2$, becomes

$$\mathrm{b} \geq \sqrt{\frac{1.5 \cdot Q_{max}}{2\tau_{allow}}} \qquad \text{or}$$

$$b \geq \sqrt{\frac{0.75 \cdot 3.60 \cdot 1000\, N}{90 \cdot 10^6 \frac{N}{m^2}}} = 0.00548\, m.$$

The number **b** of the cross-sectional **base**, being the final choice, should be the greater between the two results. Therefore **b** = 0.0302 m = **31 mm**.

4.4 Fluid Mechanics room

In the 4th room, the students are asked to solve a complex puzzle involving Fluid Mechanics problems, [28], [29], [30], [31], [32]. As soon as they enter the room the students can see a tablet, a locked box, and a faucet.

To unlock the box and see its contents, they must "match" the names of scientists to their inventions on the tablet.

- The given names are Pythagoras, Heron, Archimedes, Bernoulli, Reynolds, Ventouri followed by the images (Fig. 9).

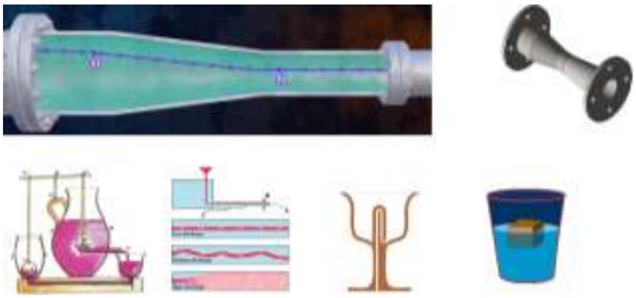


Fig. 9: Images of fluid mechanics' room

Following the correct matching of names, as shown below in Figure 10, the box is automatically unlocked while the voice "EUREKA!" is heard:

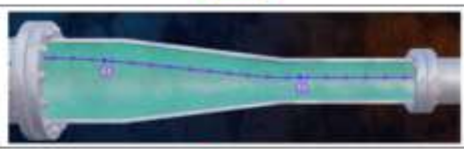
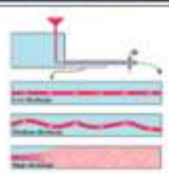
Pythagoras	
Heron	
Archimedes	
Bernoulli	
Reynolds	
Ventouri	

Fig. 10: Solution of fluid mechanics' room

Inside the box there are 3 containers with a capacity of 8 lt, 3 lt, and 5 lt together with a closed small tank of 4 lt, having a hole in its upper part (Figure 11). Both the containers and the tank do not have any indication of their water capacity. At the bottom of the small tank, there is a key that unlocks the door leading to the exit.

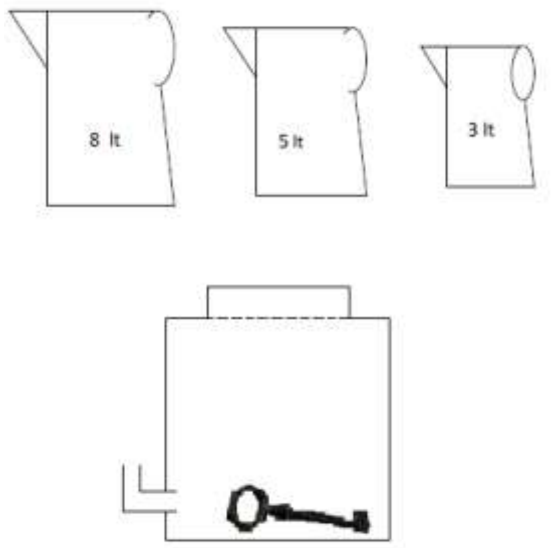


Fig. 11: Containers

To get the key, the students have to fill the tank with 4 lt of water so that the key goes up and out of the hole. They have to follow just one basic rule which is announced to them by the game expert at the entrance:

"*The faucet can be used to fill, up to 2 times the 8 lt container. The transferring of water from one container to another takes place either until the first one is empty or until the second one is full. It is not allowed to use the water of 8 lt containers to fill the tank*".

To get the key, the students should follow the following steps:

1. Fill the 8 lt container.
2. Decant 5 out of the 8 lt into the medium container.
3. From the medium container of 5 lt, pour 3 lt into the small one.

The situation in this phase is 3 lt in the large container, 2 lt in the medium, and 3 lt in the small one.

4. Empty out the small container in the faucet sink and pour the 2 lt of the middle into the small container that is now empty.
5. Refill the large container for a second time.

At this stage, we have 8 lt in the large container, 0 lt in the medium, and 2 lt in the small one.

6. From the large container having 8 lt, fill the middle one with 5 lt.
7. Pour the necessary water to fill the small container (which already has 2 lt).

In this phase we have 3 lt in the large container, 4 lt in the medium (5–1) and 3 lt in the small one (2+1).

8. Pour all the water (4 lt) of the middle container to fill the tank so that the key rises, thus enabling the escape.

4.5 Reinforced concrete room

Welcome to Reinforced Concrete's room! Here you will need to use basic knowledge of Reinforced Concrete, [33], [34], [35], [40], [41], [42], [43], [44], [45]. On the table of the room, there is a piece of paper where a retaining wall is depicted. **What is asked is the area of the bending reinforcement required at cross-section A (base of cantilever wall). You should refer to Figure 12 for a depiction of the retaining wall.**

Caution! To calculate the reactions correctly you should use the correct values for the following parameters:

μ_{sd} = Normalized bending moment
ω = Mechanical reinforcement ratio

μ_{sd}	ω	μ_{sd}	ω
0.01	0.0102	0.21	0.247
0.02	0.0205	0.22	0.261
0.03	0.0310	0.23	0.276
0.04	0.0415	0.24	0.291
0.05	0.0522	0.25	0.307
0.06	0.0630	0.26	0.323
0.07	0.0739	0.27	0.340
0.08	0.0849	0.28	0.357
0.09	0.0961	0.29	0.375
0.10	0.1074	0.30	0.394
0.11	0.119	0.31	0.413
0.12	0.131	0.32	0.434
0.13	0.143	0.33	0.455
0.14	0.155	0.34	0.478
0.15	0.167	0.35	0.503
0.16	0.179	0.36	0.529
0.17	0.192	0.37	0.559
0.18	0.206	0.38	0.592
0.19	0.219	0.39	0.630
0.20	0.233		

Table 1. For simple reinforcement (CEB)

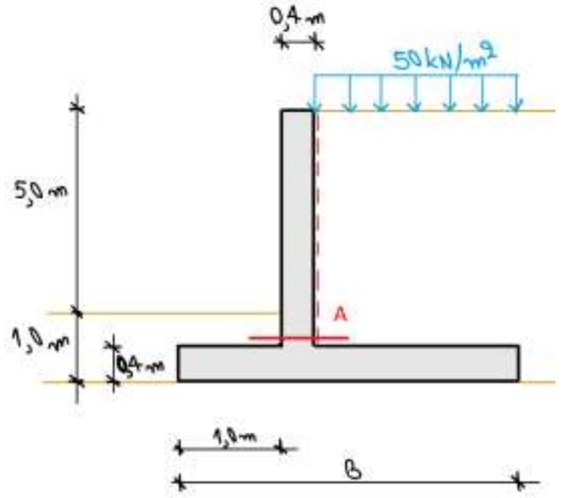


Fig. 12: Retaining wall [46]

Table 1 shows the values of the mechanical reinforcement ratio "ω" for the corresponding values of the normalized bending moment "μ_{sd}". This table is from the Comitée Euro-International du Béton (CEB) and is used for the calculation of simple (tensile only) reinforcement.

Concrete = C25/30
Steel = B500C
Axial load NA = -100 kN
Shear force VA = 200 kN
Moment = 500 kNm
Concrete cover = 5 cm
If $\mu_{sd}<\mu_{lim}$ = 0.316
→ Simple reinforcement

Then, you have to calculate the required total area of the bending reinforcement at cross-section A at the base of the cantilever of the retaining wall (with two decimal digits accuracy), which you will use as a key code to enter the next room! The correct answers that lead to the key value are shown in the calculations.

1) Depth

$$d = h - cover = 0.40 - 0.05 \Rightarrow \mathbf{d = 0.35\ m}$$

2) Bending moment

$$M_{sd} = M_d - N_d \cdot \left(d - \frac{h}{2}\right) = 500.00 - \left[(-100) \cdot \left(0.35 - \frac{0.40}{2}\right)\right] \Rightarrow \mathbf{M_{sd} = 515.00\ kNm}$$

3) Normalized bending moment

$$\mu_{sd} = \frac{M_{sd}}{b \cdot d^2 \cdot f_{cd}} = \frac{515.00}{1.00 \cdot 0.35^2 \cdot \frac{25 \cdot 10^3}{1.5}} \Rightarrow$$

$$\Rightarrow \mathbf{\mu_{sd} = 0.252 < \mu_{lim} = 0.316 \rightarrow Simple\ reinforcement}$$

4) Required area of reinforcement

$$\mu_{sd} = 0.252 \xrightarrow{\text{Table for simple reinforcement}} \mathbf{\omega = 0.3102}$$

$$A_s = \omega \cdot b \cdot d \cdot \frac{f_{cd}}{f_{yd}} + \frac{N_d}{f_{yd}} = 0.3102 \cdot 100 \cdot 35 \cdot \frac{\frac{25}{1.5}}{\frac{500}{1.15}} + \frac{-100}{\frac{500 \cdot 10^{-1}}{1.15}} \Rightarrow \mathbf{A_s = 39.32\ cm^2}$$

4.6 Databases room

Welcome to Databases room!

In this last room, the students are asked to design the best database schema for engineering hall of fame, [36], [37], [38].

Relation Engineer is given, which concerns famous professionals who design the processes for and build products, machines, and structures that changed the world and brought innovation to our lives. Specifically, the Engineer table stores data about engineers and their contributions.

Engineer relation has the following attributes: Name, Profession, BirthYear, BirthCountry, DiedYear, InventionName, InventionDescription, InventionYear, EngineeringField.

Semantically, it is specified that one engineer with a unique name may have made several different inventions over the years. Different engineers may have made an invention with the same invention name belonging in the same engineering field. For example, a snapshot of this relation is given in Table 2.

Name	Profession	Birth Year	Birth Country	Died Year	Invention Name	Invention Description	Invention Year	Engineering Field
Parker Alice	Inventor	1895	United States	1920	Central gas heating	System of central heating using natural gas	1920	Electrical engineering
Tesla Nikola	Electrical and mechanical engineer	1856	Croatia	1943	Electric arc lamp	Arc lamp with carbon electrodes controlled by electromagnets or solenoids and a clutch mechanism; Corrects earlier design flaws common to the industry.	1886	Electrical engineering
Tesla Nikola	Electrical and mechanical engineer	1856	Croatia	1943	Electro Magnetic Motor	Novel form and operating mode; Coils forming independent energizing circuits; Connected to an alternating current generator; Synchronous motor.	1888	Electrical engineering
Lovelace Ada	Mathematician	1815	England	1852	First computer programme	Description of how the proposed Analytical Engine could be programmed to compute Bernoulli numbers.	1843	Computing engineering
Thomas Edison	Businessman	1847	United States	1931	Light bulb	Combination of three factors: an effective incandescent material, a higher vacuum than others were able to achieve (by use of the Sprengel pump) and a high resistance that made power distribution from a centralized source economically viable.	1879	Illuminating engineering
Thomas Edison	Businessman	1847	United States	1931	Motion picture camera	Motion picture exhibition device, designed for films to be viewed by one person at a time through a peephole viewer window.	1888	Electrical engineering
Thomas Edison	Businessman	1847	United States	1931	Phonograph	Record player, instrument for reproducing sounds by means of the vibration of a stylus, or needle, following a groove on a rotating disc.	1877	Mechanical engineering

Table 2. Snapshot of *Engineer* relation

1. Which functional dependencies apply to relation *Engineers*?
2. What is the primary key of this relation?
3. In which normal form (NF) is a relation *Engineer*? Justify your answer and also explain why it is not in the next normal form.

4. Convert this relation to normal form BC (BC-NF). Underline the primary key in each new relation that arises.

Answers:

1. The functional dependencies that apply to this relation are:

Name, InventionName -> InventionDescription, InventionYear

Name -> Profession, BirthYear, BirthCountry, DiedYear, InventionName

InventionName -> EngineeringField

2. PK (primary key): Name, InventionName (composite PK)

3. Relation Engineer is in 1NF since the value of any attribute in a tuple is a single value.

It is not in 2NF since it contains partial dependencies, i.e. there are functional dependencies between attributes that are not part of the PK and a part of the PK, e.g. the functional dependences Name -> Profession, BirthYear, BirthCountry, DiedYear, InventionName, and InventionName -> EngineeringField.

4. The relation is converted to NF-BC by creating three projections from the original Engineer relation. The three projections are:

Engineer1

Name	InventionName	InventionDescription	InventionYear

Engineer2

Name	Profession	BirthYear	BirthCountry	DiedYear	InventionName

Engineer3

InventionName	EngineeringField

They are all in KM-BC since the only functional dependencies are from the PK (underlined) to the other attributes.

4 Conclusions

The obtained results of the escape room game can be classified into three categories:

a. the satisfaction with the correct answers to the puzzles that appear in each room, which is a result of the existing knowledge that each member of the group has,
b. the experience acquired after each participation, that differs from those obtained by other scientific methods (teaching, testing, etc.), and
c. the adaptability and cooperation of the team members are also an undeniable positive characteristic that can appear as a result from teamwork.

The conclusions arising from the above game are:

1. Through the escape rooms the student acquires the feeling of cooperation, teamwork, strategy, skill, and knowledge acquisition.
2. The process of solving puzzles in an escape room is essentially a collaborative problem-solving process in which players exchange information, access different elements at the same time, and use a variety of skills and knowledge.
3. The above examples clearly show that the interactive process that is followed for the Evaluation of Engineering Knowledge –and for the needs of the present work is simply represented by six modules/rooms – is beneficial for every single branch of engineering.
4. Therefore, a similar procedure could well be applied not only to Mechanical, Civil, Chemical, Surveyors, Mineral Resources, Naval Engineers etc. but, in our view, to all other branches of science.
5. Thematic calculations are made according to the teaching of the course at our institution, where the prospective competing students come from. For another institution, the data and the way of solving, therefore the answers, may be different.

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