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Improve The Bearing Capacity of Reinforced Concrete by Using Small Springs.

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Abstract

Invented in 1824 by Joseph Aspdin, concrete is now widely used in construction as well as in other areas of social life. There are many studies on changing the structure and materials of concrete This paper focuses on reducing the size of concrete and increasing its bearing capacity. To achieve this, the paper's author proposes a theoretical model related to the physical nature of the load-carrying particles. External forces generate the load-carrying particles. If these particles are absorbed, the load-carrying capacity will increase. In a typical load-bearing situation, the total maximum load-carrying particles are constant. Therefore, only by gradually absorbing these particles through small springs will the goal of ensuring designers get structural durability. Previous construction designers based on durability theories, this paper proposes a new design principle. This approach achieves the proposed goal. The paper's results also serve as a basis for supporting future designers and contribute to rationalising other issues such as cost, environment and time.

Keywords: concrete, beam, springs, force, small, absorption, energy.

1. Introduction

1.1 World cement consumption situation

Along with the development of the economy, more people are living in buildings. Reinforced concrete is widely used in these buildings and is the main load-bearing structure. Concrete is made by mixing cement, sand, stone, additives, and water in a specific ratio depending on the grade. Reinforced concrete is poured into a mould with pre-set reinforcement and then waited to set. After that, users work with finished concrete.

Vol. 10, No. 03; 2025

ISSN: 2456-3676

Because the amount of cement used in concrete is directly related to its formation, cement data can visualize the current situation of concrete use worldwide.

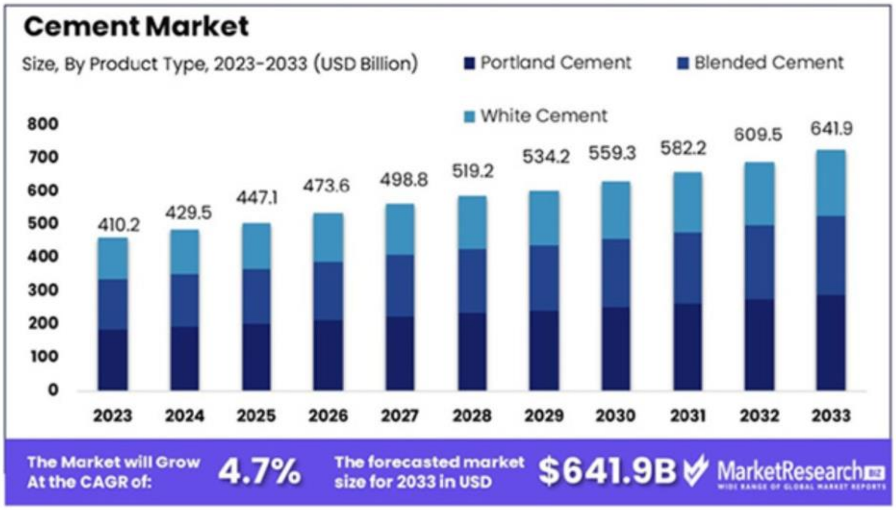

Figure 1. Cement market all over the world [15]

The chart above shows that the demand for cement has increased over the years. The total value of cement in 2023 was 410.2 billion dollars, and forecasting will rise to 641.9 billion dollars in 2033. To be more explicit, we will look at the countries that produce the most cement today: Vietnam, India, and China.

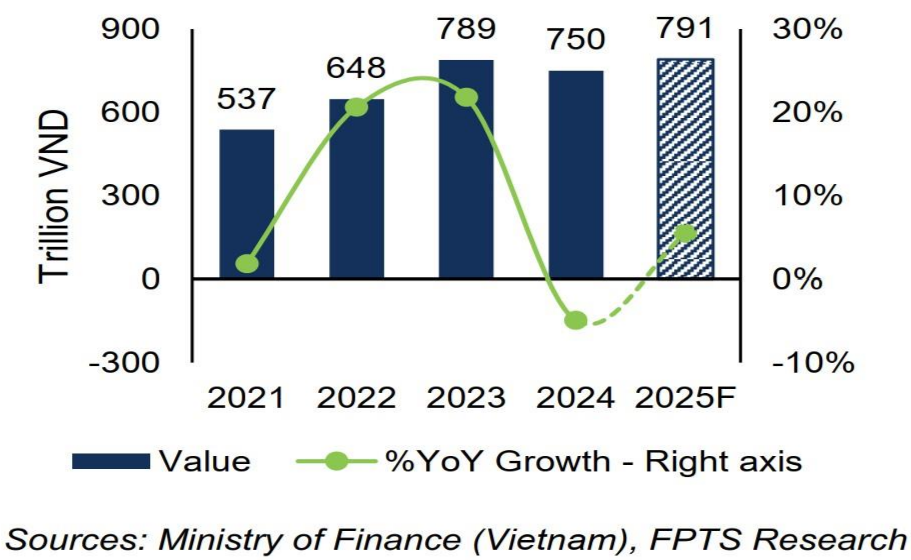

Figure 2. Vietnam government plan for public capital disbursement from 2021 to 2025F [15]

Government investment in 2022 - 2024 and forecast for the end of 2025 are over 600 trillion VND (about 24 billion USD). In 2021, due to the COVID-19 pandemic affecting the whole world, including Vietnam, investment decreased but immediately increased.

Figure 3. Vietnam cement industry cycle.

Regarding Vietnam's consumption and export output, although there are different increases and decreases over each period, the annual total production (from 2015 and forecast to the end of 2025) is over 70 million tons.

Like Vietnam, China, India is a cement production powerhouse worldwide.

Table 1 – Capacity Utilization by by Cement Industry. [21]

Year	Production (Million tonnes)	Cement: Capacity Addition (Million tonnes)	Cement: Outstanding Capacity (Million tonnes)	Cement: Capacity Utilisation (%)
2015-16	273.9	15.54	495.32	62.1
2016-17	270.4	28.09	523.41	58.4
2017-18	288.0	21.42	544.83	60.0
2018-19	327.7	15.54	495.32	66.2
2019-20	327.3	28.09	523.41	62.5
2020-21	284.9	21.42	544.83	52.3
2021-22	350.6	31.62	576.45	60.8

Source: CMIE, Infomerics Economic Research

The above data shows that from 2015 to 2022, output is always over 270 million tons.

Vol. 10, No. 03; 2025

ISSN: 2456-3676

Table 2: Production and Consumption of Cement in India ('000 tonnes) [21]

Year	Production	Consumption
2011-12	223,500.00	222,378.70
2012-13	240,614.00	240,387.60
2013-14	249,826.00	247,480.30
2014-15	261,338.00	257,412.60
2015-16	273,857.00	271,243.50
2016-17	270,375.00	266,823.50
2017-18	287,964.00	284,721.20
2018-19	327,722.00	324,927.90
2019-20	327,266.00	327,928.90
2020-21	284,913.00	285,308.90
2021-22	350,595.00	351,071.90
2022-23	374,558.50	375,190.70

Source: CMIE, Infomerics Economic Research

At the same time, consumption output is also approximately equal to production capacity. China is currently the world's leading country in cement production.

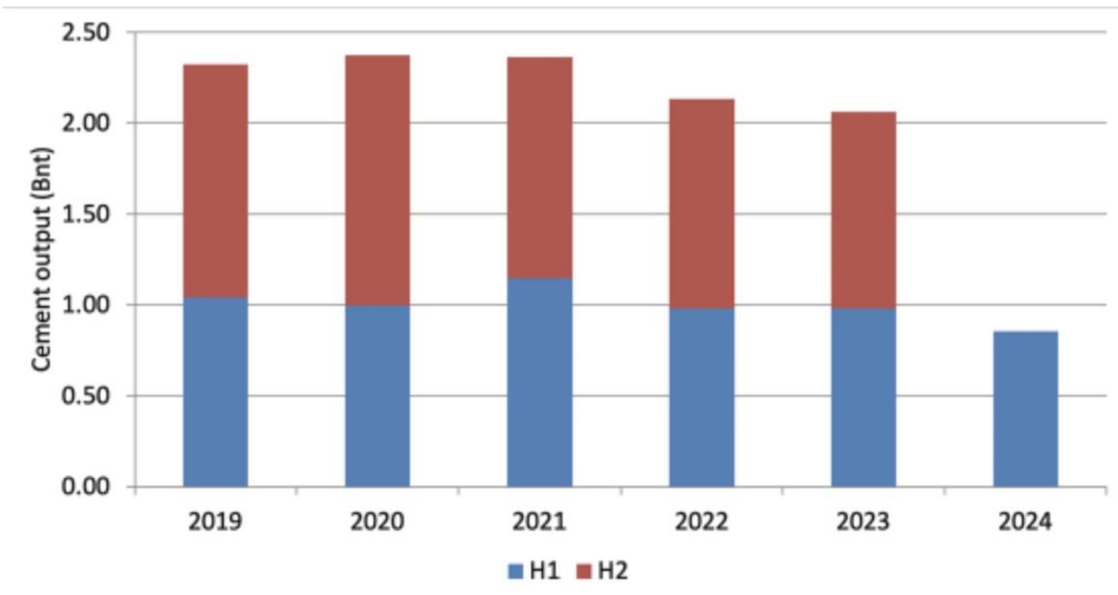

Figure 4 - Cement products in China (sources: National Bureau of Statistics of China (NBS)) [12] From 2019 to the first half of 2024, China will consistently produce over 2 billion tons of cement.

The above figures show that cement is an indispensable input material in concrete production. The output is up to billions of tons per year worldwide. Any impact related to concrete structures significantly impacts the economy, nature, environment, and society. Therefore, changing the reinforced concrete structure to be more reasonable is ***urgently needed.***

Vol. 10, No. 03; 2025

ISSN: 2456-3676

1.2 Technologies used today

With current technology, reinforced concrete structures mainly withstand compression. Therefore, the stress and internal force generated in each steel and concrete element also correspond to this compressive capacity. Current technologies using the compressive capacity of concrete in the world:

• In hydropower construction:
- Roller compacted concrete.
- Poured concrete technology.
- Arch dam construction technology

• Civil and industrial:
- Slip formwork technology
- Prestressed concrete technology
- Self-compacting concrete.

For changing concrete, thereby changing the load-bearing capacity, there are the following technologies:

• Lightweight concrete (or foamed concrete):
- Durability remains unchanged
- Reduces construction time
- Mainly used for making floors and slabs, not used to make load-bearing beams.

• Fine-grained concrete:
- Made from dunes and thermal power ash. Therefore, it reduces weight and is environmentally friendly.
- Tensile and bending resistance, smoother surface, better waterproofing.
- Suitable for high steel density and production of precast, thin-walled products.

*As mentioned, although there have been improvements to the concrete itself, they have mainly focused on separate issues. That is, lightening the concrete or changing the grain size, thereby changing the strength. There has been no research that combines **both lightening and increasing working strength**. Changing the reinforced concrete structure makes the internal forces generated after the change tensile, compressive, bending, and torsion simultaneously. In addition, under the effect of spring, the external forces generated in each spring cancel each other out. They are absorbed when doing work. Thereby, it increases the bearing capacity and reduces the mass of concrete.*

1.3 Current design principles.

In civil engineering design, strength theories are used to evaluate the load-bearing capacity and durability of materials under various conditions. Some fundamental strength theories include:

- Maximum Normal Stress Theory: Based on the assumption that materials fail when the maximum normal stress reaches their strength limit.
- Maximum Strain Theory: Considers the maximum relative strain of materials under complex stress states compared to simple stress states.

Vol. 10, No. 03; 2025

ISSN: 2456-3676

- Maximum Shear Stress Theory: Evaluates the material's load-bearing capacity using the maximum shear stress, commonly applied to ductile materials.
- Strain Energy Theory: Examines the strain energy of materials to determine strength conditions.
- Distortion Energy Theory: Widely used in mechanical engineering and construction, particularly suitable for ductile materials.

When designing according to the ***new principle****, the project also meets the requirements if the structure is durable enough.*

2. Method

2.1 Principle of the method

As mentioned, the design principles mainly used stress and deformation. But in the end, the deformation that causes structural destruction occurs because the stress generated at the destruction location exceeds the allowable value at the time of geometrical deformation destruction.

Newton's 2nd law states that: $F = ma\ (N)$
- F: force (N);
- m: mass;
- a: acceleration (m/s^2).

The dimensions and time are two factors that create acceleration and force. If a worker can control these factors, F will gradually disappear, which means that the power created by the external force is dissipated.

Changing motions create acceleration (i.e. generate force). So, absorbing these motions also absorbs force.

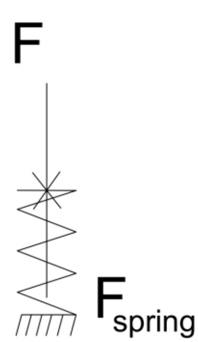

Figure 5. Diagram showing the force absorption capacity of a spring Force-carrying particles have the following properties.

Vol. 10, No. 03; 2025

ISSN: 2456-3676

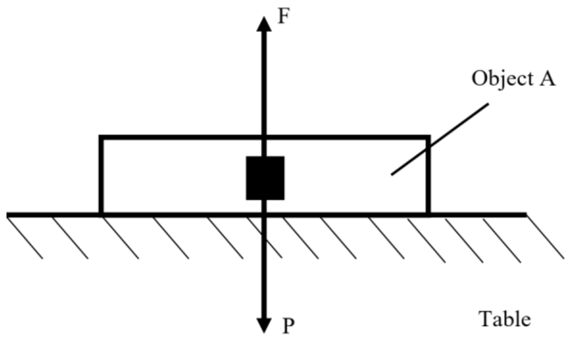

Figure 6. Description of the existence of force-carrying particles

When placing object A on the table, force P cancels out reaction force F; when lifting A off the table, F also disappears.

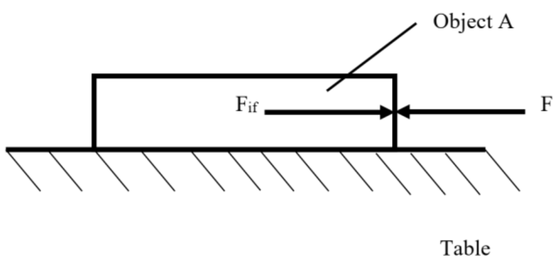

Figure 7. The object is in motion even when there is no force applied.

When a force F is applied to object A, the inertial force Fif generated will cancel out the force F. If the force F stopped, F_{if} will also disappear.

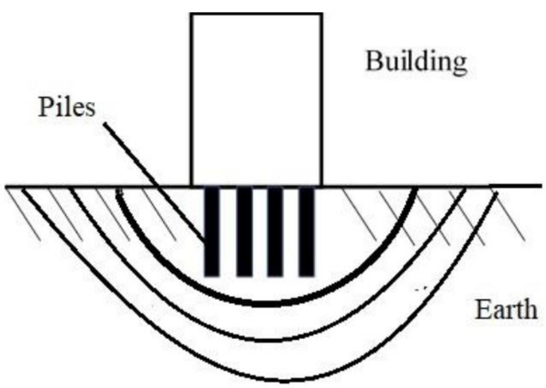

Figure 8. The force of the building on the ground reaches zero in the infinite half lane.

Vol. 10, No. 03; 2025

ISSN: 2456-3676

A building is constructed, and the improved foundation is made of piles. The curves represent locations where the force-carrying particle density is the same. The density is lower for larger the curves. At some point, the curve disappears.

Formula for calculating normal stress in material mechanics:

$\sigma = F / A$ (1)

Where:

σ: Normal stress (N/m² or Pa).

F: Force acting perpendicular to the cross-section (N).

A: Cross-sectional area (m²).

Formula for calculating shear stress in material mechanics:

$\tau = (T / J) \times r$ (2)

Where:

τ: Shear stress (N/m² or Pa).

T: Torque moment (Nm).

J: Polar moment of inertia of the cross-section (m⁴).

r: Distance from the center to the point where stress is calculated (m).

The above formulas express the density of force-carrying particles per unit area. There are two options to dilute the density of force-carrying particles, which are:

+ Reduce the external force value
+ Increase the cross-sectional area.

In addition to the above two options, the author proposes reducing the density of particles by adding small-sized elastic springs to the concrete structure.

2.2 Illustrative example.

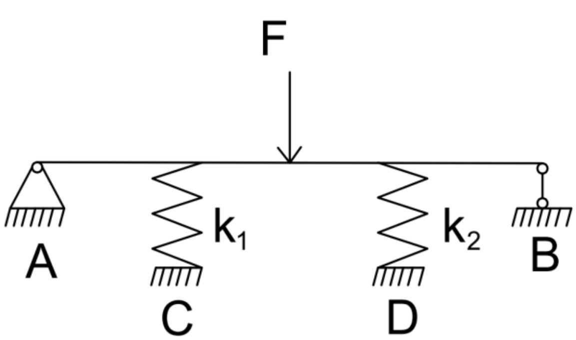

Figure 9. Diagram illustrating the load-bearing structure of a beam without springs mixed into the concrete

Instead of placing springs k_1 *and* k_2 ***outside as in the calculation diagram, small springs with total values equivalent to*** k_1 *and* k_2 ***can be added directly into the concrete mixture to make the***

ISSN: 2456-3676

beam. Beam AB will, therefore, have a simpler structure. The two supports, C and D, are no longer necessary, and springs k_1 *and* k_2 ***also disappear.***

Survey of reinforced concrete beams with dimensions 250 x 250 x 4000 mm. With the following parameters:

Table 3 – Value of the parameter.

Parameters	**Value**
Concrete	250
Compressive strength	110 (kG/cm^2)
Reinforcement strength	2700 (kG/cm^2)
Specific weight	2500 (kG/m^3)
Module of elasticity	2,65.10^6 (kg/m.s^2)
Poisson's ratio	0.2
Coefficient of thermal expansion	9.9.10^{-6}
Shear modulus	1104166.7

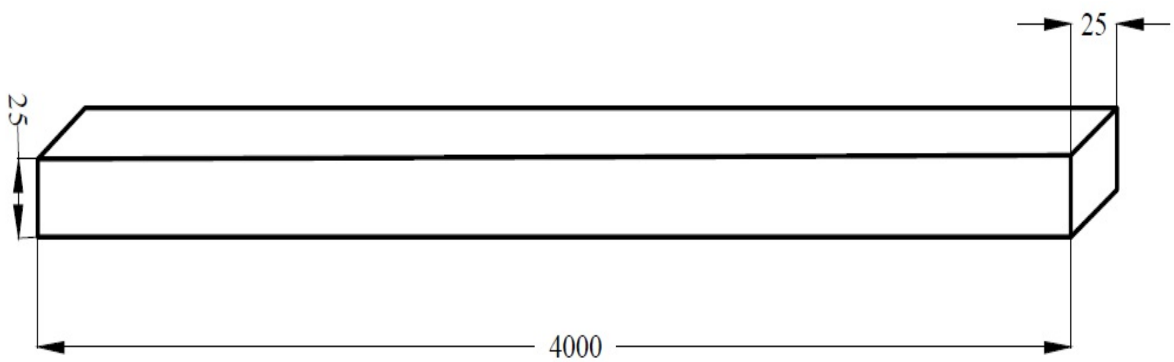

Figure 10 - Example diagram of research beam.

This reinforced concrete beam is placed on two supports and bears a force F = 10000 (N) in the middle of the beam. The calculation diagram is as follows:

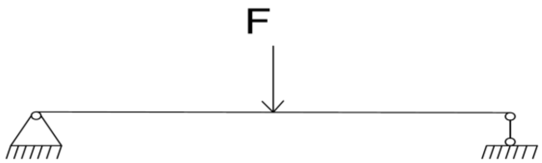

Figure 11 – Beam calculation diagram.

This concrete beam has the following characteristics:

Vol. 10, No. 03; 2025

ISSN: 2456-3676

The distance from the edge of the section to the center of gravity of the upper and lower reinforcement is 4 cm.

The allowable deflection of this reinforced concrete beam is:

$$f_{df} = \frac{l}{150} = \frac{4000}{150} = 26(mm) \qquad \textbf{\textit{(3)}}$$

In the above formula: l - span (l = 4m = 4000 mm)
Using Sap2000 software to calculate the following results:
- In the case of no force F, the deflection due to the concrete's weight is 0.8 mm
- In the case of force F = 1000 kg, the deflection will be 9.3 mm

The load-bearing situation in the reinforced concrete structure of the beam (Figure 11) is very complicated. The internal forces generated in the structure cause tensile, compression, bending, and torsion, the central part of which is compression.

Use springs with stiffness k = 1/9 (N/mm). Mix into the reinforced concrete mixture of the concrete beam with the above parameters.

However, if the concrete has small springs (like ballpoint pen springs) mixed, the springs will be evenly and randomly distributed in any direction, increasing the load-bearing capacity.
Proposing the technical parameters of these springs as follows:

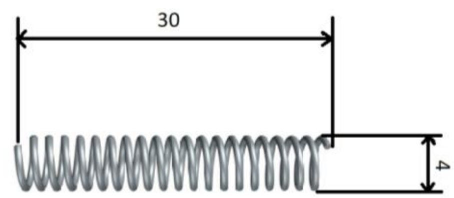

Figure 12 – Description of the spring under study.

Spring wire diameter: d = 4 mm
Maximum tensile strength: l_{max} = 8.5 mm
Natural length l_0 = 30 mm.
Number of steps: 20
Spring wire radius: r = 0.2 mm
Spring stiffness is: $k = \frac{10^3}{9}(N/m)$

Vol. 10, No. 03; 2025

ISSN: 2456-3676

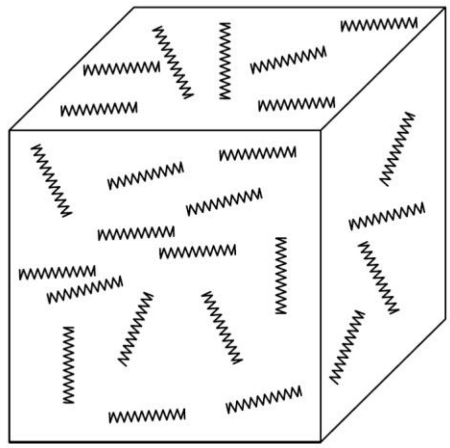

Figure 13 – Describing the random distribution of springs in space in an element.

The above figure describes the removal of a concrete element in which the springs are randomly distributed. According to Hooke's law of elasticity, springs can be combined in three forms: series, parallel, and mixed. It is easy to see that the springs in concrete combined in parallel. The combination diagram has the form described below.

The spring's bearing capacity can be modelled as follows:

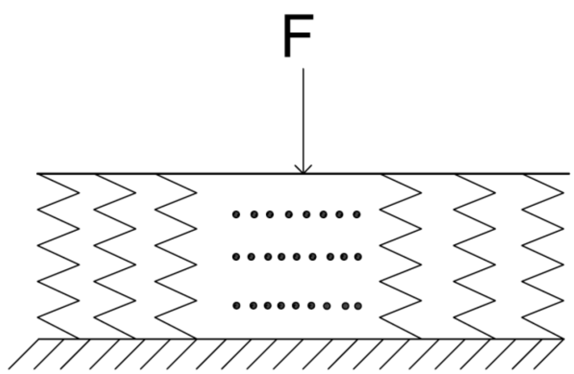

Figure 14 – Calculation diagram for spring system subjected to tension and compression in concrete.

In this diagram, the spring can withstand tension and compression in addition to bending and torsion, but the force causing bending and torsion is very small, so the designer can ignore it.
In the simple beam diagram of Figure 11, according to the principle of combined effects, assuming that the deflection of the beam f_{df} = 26 (mm), force F = 10000N. When the force acts on the beam, it generates a work:

$$A = 10000x(9{,}3-0{,}8).10^{-3} = 85\ (J) \qquad (4)$$

Vol. 10, No. 03; 2025

ISSN: 2456-3676

Suppose the work A is wholly absorbed in the springs. According to the law of conservation of energy, it is clear that the possibility of destroying the beam will decrease. We have the following equation:

A = k.Δl² = 85 (J). ***(5)***

$$\Delta l = \sqrt{\frac{85}{\left(\frac{1}{9}\right)10^3}} = \sqrt{0,87} = 0,94(m) \qquad (6)$$

(Δl – spring tension or compression length)
Assuming that the concrete operates within the elastic limit.

$$\varepsilon_b = \frac{\Delta l}{l} = 2.10^{-3} \qquad (7)$$

$$\Rightarrow \Delta l_{sp} = \varepsilon_b.l_0 = 2.10^{-3}.30 = 0,06(mm) \qquad (8)$$

ε_b : Proportional elongation of spring.

Then, the spring stretches or compresses a section$\Delta_{lv} = 0,06(mm)$. So, the number of springs that need to be mixed into the concrete in the beam under consideration is:

$$N = \frac{0,94}{0,06.10^{-3}} = 15666(springs) \qquad (9)$$

Thus, the average density (AD) of the spring is:

$$AD = \frac{N}{0,25\times 0,25\times 0,25} = \frac{15666}{0,25} \qquad (10)$$

$$AD = 62664(springs/\mathrm{m}^3)$$

The density of the spring on a beam element with dimensions of 0.25m x 0.25m x 0.25m is:

$$AD_{0,25} = 62666\times 0,25^3 = \frac{62666}{64} \qquad (11)$$

$$AD_{0,25} = 979,1(springs/0,015625\ \mathrm{m}^3) \qquad (12)$$

With the number of springs inserted as above, it can withstand 10000 (N), and the steel structure of traditional reinforced concrete itself can withstand 10000 (N). At the same time, the structure is capable of withstanding tension, compression, bending, and twisting. Therefore, there is no need to change the steel structure of the concrete when the load-bearing situation changes.
The volume of steel material to make one spring:

$$V = 20.\pi.d.\pi r^2 \qquad (13)$$

In which d = 4 mm, r = 0.2 mm.

$$V = 17,747(mm^3)$$

Vol. 10, No. 03; 2025

ISSN: 2456-3676

So the total volume of the spring in an element P = 250 mm x 250 mm x 250 mm will be:

$$\sum V_{sp} = 979{,}1 \times 17{,}747 = 17376{,}1(mm^3) \qquad \textbf{\textit{(14)}}$$

The total mass of the spring in P will be:

$$\sum m_{sp} = \sum V_{sp} \times \rho = 17376{,}1 \times 10^{-9} \times 7800 = 0{,}0136(kg) \qquad \textbf{\textit{(15)}}$$

The mass of the concrete in P will be:

$$m_P = \rho_{concrete}.250.250.250.10^{-9} = 39{,}06(kg) \qquad \textbf{\textit{(16)}}$$

The mass of the concrete corresponding to the part of the spring occupying space in P is:

$$m = \sum V_{sp} \times \rho_{concrete} = 17376{,}1 \times 10^{-9} \times 2500 \qquad \textbf{\textit{(17)}}$$

$$m = 0{,}0434(kg)$$

Thus, compared to traditional concrete, concrete with springs will be heavier:

$$\%T = \frac{0{,}0434 - 0{,}0136}{39{,}06} \times 100\% \approx 0{,}08(\%) \qquad \textbf{\textit{(18)}}$$

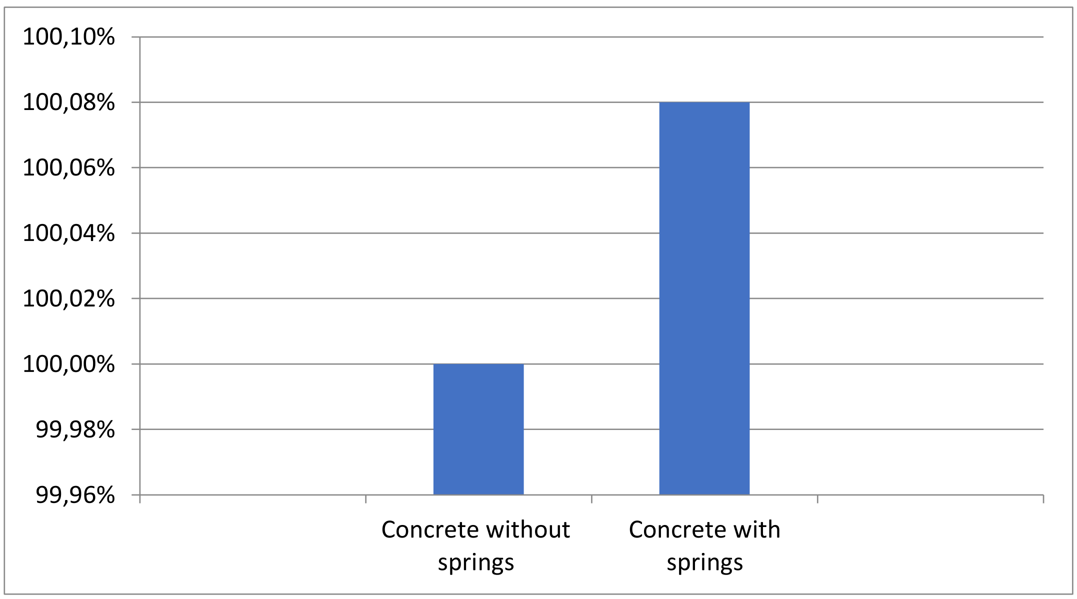

Figure 15 – Graph describing the effect of the mass of concrete with springs, compared to concrete without springs.

3. Results

During the research, we obtained remarkable results related to the increase in bearing capacity. Firstly, the new principle clarified the relationship between the absorption of force carriers and the rise in strength. Besides, we found that adding small springs would increase the strength of the structure.

The descriptive drawings and calculation examples presented in the research demonstrated the problem's correctness. In addition, this example ensures the solidity and feasibility of the findings.

4. Discussion

The results of this study show that reducing the mass of concrete while increasing its bearing capacity is entirely feasible, making an essential contribution to a deeper understanding of concrete. The finding is consistent with previous studies of other studies but also provides new aspects related to design principles. These findings support the hypothesis's validation and suggest further research directions, such as rewriting computer calculation software. However, some limitations of the study should be considered, such as the need for additional large-scale practical tests to confirm the correctness of the problem further. If the test results are confirmed to be reasonable, the accuracy and broad application of the research results will be an opportunity to promote other important issues.

5. Conclusion

In this study, we have explored what seemed to be an absurdity. The results not only shed light on the principle of carrier absorption but also opened up the prospect of further research on its application to other problems. Although there are some limitations, these results provide a solid foundation for additional development. Therefore, further research will provide opportunities to enhance understanding of the research topic and, at the same time, promote progress in other fields.

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