

Technical and Economic Feasibility of Using Steel Fibers Reinforced Concrete (SFRC) in Slap line of Subways and Rail Roads

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Abstract-Utilization of steel fiber in railroad is under consideration in some countries around the world. The purposes of using these materials are, increase of freightage and crack control in the slap of the subway and railroad line. Fibers are commercially available and manufactured from steel, plastic, glass, and other natural materials. In many situations it is prudent to combine fiber reinforcement with conventional steel reinforcement to improve performance. The model of concrete can be used for analysis of failure mechanism of reinforced concrete structural elements. Although most of the current railway tracks are still of a traditional ballasted type and recent applications tend more and more towards non-ballasted track. Slab track designs have significant advantages comparing to ballasted tracks. The most significant are the high stability of the track. Their disadvantages against the ballasted tracks are mainly summarized in their higher construction costs. In order to select the most suitable concrete for the construction of high-rise buildings, method of analytic hierarchy process based on expert knowledge has been used. In this study conducted a series of laboratory works, to compare the effect of steel fibers used in various categories of resistance on concrete behavior parameters. Mixing the samples is set for the three categories of resistance 25, 35 and 45 MPa. Strength parameters that are chosen to identify concrete actions are tensile strength, impact strength, compressive strength, and flexural strength. Also, the samples in each resistance category are made with four fibers quantity: without fibers, 15, 25 and 35 kg fibers per cubic meter. The results suggest that using of steel fibers, increases the impact resistance, time of the first crack and ultimate strength of concrete significantly. Also, the addition of this type of fibers, increases tensile strength and flexural strength but doesn't have significant effect on the compressive strength of concrete.

Keywords-Steel Fiber in concrete, Crack Control, High Performance, High Strength, Durability, Tension, Failure, Non-Ballast Track, freightage, Stability, Cost.

I. INTRODUCTION

In the last 40 years, increase in train speed and axle load around the world and other challenges in the conventional ballasted track system gave birth to ballastless railway track system (1). Using Non-Ballast railway especially in tunnels and bridges, due to the altitude drop of the railroad line, reduce maintenance, and total cost, facilitate higher train speed, and increase of lateral resistance are widely increased.

A comparison between ballasted and ballastless tracks is essential in order to clearly identify when and where the slab track systems perform better. In many cases slab track systems seem to have the capabilities to serve these high-speed routes more efficiently than the ballasted tracks mainly due to their higher structural stability, significantly lower need of maintenance, and longer life cycle. One of the issues that can be considered, as a disadvantage of this type of pavement, is armature.

Discussion in terms of exploitation is cracks caused by passing load and the environment situation.

One of the ways to prevent these problems is the utilization of steel fiber in construction of slab lines. Fibers are produced from different materials in various shapes and sizes. Using fibers in concrete is to improve the characteristics of construction materials (2).

The idea of adding fibers to fragile blends that have little tensile strength has existed since ancient times. The old Egyptians used straw to arrange mud bricks (3). In the past, they used to use short pieces of dried herbs with water and soil as a mixture of clay, to build wall and brick.

The fibers are in use for crack control in effect of volumetric changes due to contraction, expansion, thermal stresses, increase of tensile strength, softness, energy absorption capability and provide an integrated system. Currently, hundred types of fibers as herbal,

artificial and metal are producing that only some of them are suitable to use in concrete (4).

II. DIFFERENT TYPES OF FIBER

According to the origin of fibers, they are classified in three categories of Metallic fibers (Such as steel, carbon steel and stainless steel), Mineral fibers (such as asbestos and glass fibers) and Organic fibers (5).

1. Organic Fiber:

Organic fibers can be natural and manufactured. Natural fibers can be vegetable origin or sisal (such as wood fibers and leaf fibers) and animal origin (such as hair fibers and silk). Man-made fibers can also be divided into two groups as natural polymer (such as cellulose and protein fibers) and synthetic (such as nylon and polypropylene) (5). The ability of the concrete improvement in these fibers depends on their length, appearance, and tensile strength. However, their tensile strengths are lower than other fibers, usually cause failure in concrete structure and do not have volumetric stability against humidity.

2. Mineral Fiber:

The mineral fibers were available after the establishment of the petrochemical industry. Some of these fibers are in different industries, like production of textiles and use to resist some parts of car and airplane industry.

In addition, they used to refine the material of the paper. Other petrochemical products are chlorine and polypropylene that countries like Canada, Japan, and USA use (5).

3. Steel Fiber:

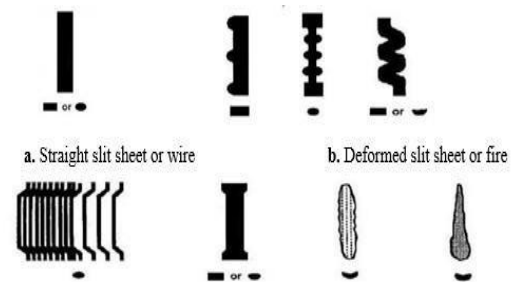
Steel fiber is more practical than others are. The reasons for these issues are as follow (5):

- Steel fiber creates the highest increasing in resistance and plasticity.
- They are producible to different appearance for improve concrete behavior.
- It is easy to do to mixture of them with other concrete materials.

Steel Fiber Reinforced Concrete (SFRC) is classified based on its fiber volume percentage as follow:

- Very low volume fraction of steel fiber (SF) (less than 1% per volume of concrete),
- Moderate volume fraction of SFs (1÷2% per volume of concrete),
- High volume fraction of SFs (more than 2% per volume of concrete).

3.1 Shapes of Steel Fiber: We have different shapes of steel fiber that depend on production and raw materials like smooth, rippling, bent and rounded, oval, rectangle, crescent, and so on.



c. Crimped-end wire d. Flattened-end slit sheet or wire e. Machined chip f. Irregular fiber
Fig 1. Different shapes of steel fibers (5) (ACI544.IR, 1996).

3.2 SFRC Benefits:

The beneficial influence of SFs in concrete depends on many factors such as type, shape, length, cross section, strength, fiber content; SFs bond strength, matrix strength, mix design and mixing of concrete.

The addition of SFs in the conventional reinforced concrete (RC) members has several advantages such as (5):

- SFs increase the tensile strength of the matrix, thereby improving the flexural strength of the concrete.
- The crack bridging mechanism of SFs and their tendency to redistribute stresses evenly throughout the matrix contribute to the post- cracking strength and restraining of the cracks in the concrete.
- Increase ductility of the concrete.
- SFRC is more durable and serviceable than conventional RC.

3.3 Mechanical Properties of Steel Fiber:

The crack-arrest and crack-control mechanism of SFs has three major effects on the behavior of SFRC structures (6).

- The addition of SFs delays the onset of flexural cracking. The tensile strain at the first crack increases until 100% and the ultimate strain may be 20÷50 times larger than for plain concrete.
- The addition of SFs imparts a well- defined post-cracking behavior to the structure.
- The crack-arrest property and the consequence increase in ductility impart a greater energy absorption capacity (higher toughness) to the structure prior to failure.

3.3.1 Compressive Strength: Johnston (1974) and Dixon and Mayfield (1971) found that an addition of up to 1.5% of SFs by volume increases the compressive strength until 15% (5). Figure 2 shows the relationship between the compressive strength and steel fiber volume fraction and aspect ratio.

It clearly demonstrates that the compressive strength increases with increasing fiber volume fraction and aspect ratio. However, it shows a relatively lower rate of increase.

Under uniaxial compressive, vertical compressive and transverse tensile strain occurred in concrete compressive strength test specimens and the concrete deformation continuously increased with increasing of load. When the compressive load was increased, cracks that occurred in coarse aggregate extend and propagate into cement paste. When the compressive load reached a certain level of strength, concrete failure occurred. Concrete compressive strength increased with increasing aspect ratio of the fiber.

Compressive strength does not benefit very much from a further improvement in matrix strength. The improvement of compressive strength of high strength, lightweight concrete with the addition of steel fiber was little. Meanwhile, the tensile/compressive strength ratio was obviously bigger. These were attributed to the effect of the steel fiber arresting cracking (7).

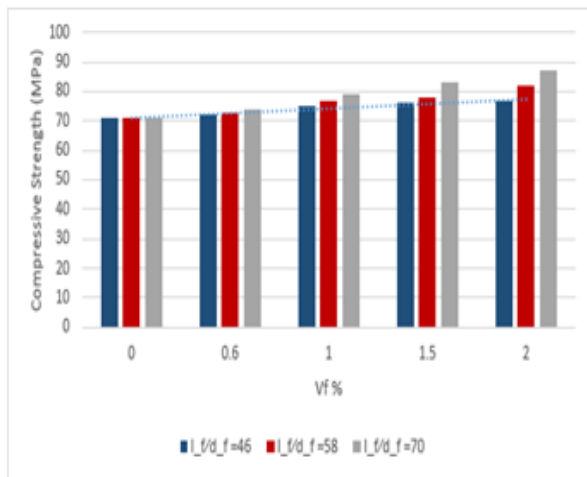


Fig 2. Effect of V_f and l/d on compressive strength.

3.3.2 Shear Strength: SFs substantially increases the shear strength of concrete. The ultimate shear strength of SFRC containing 1% by volume of SFs increases up to 170% compared to RC without SFs. The addition of SFs completely replaces the traditional transverse shear. Rather than using a single type of SF, a combination of SFs with various aspect ratios is more effective in improving the mechanical performance of SFRC (5, 8).

3.3.3 Durability: Corrosion in concrete structures due to the cracks is less severe in the SFRC structures compared to conventional RC ones (5). Steel fiber increases durability in concrete by reduction in the cement paste content. Durability and other characteristics of concrete depend upon the properties of its ingredients, the mix properties, the method of compaction and other controls during placing, compaction and curing.

Adding fibers in concrete increase its durability against chemical attacks (9). The measurement of concrete electrical resistivity can give an indication of concrete durability.

Figure 3 shows the relationship between the concrete electrical resistivity and curing ages and indicates the reduction of concrete electrical resistivity with the increase in the percentage of SFs due to the conductivity of the fibers.

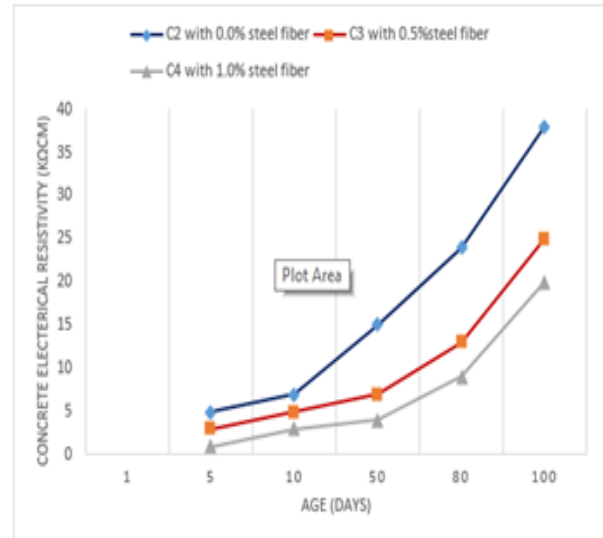


Fig 3. Effects of Fibre Content on Concrete Electrical Resistivity.

III. METHOD OF FIBER PERCH

The method of fiber perch in the crack axis is effective in the power transmission to the crack level. The fibers that are parallel to the crack do not help the power transmission. But the fibers indicate the maximum impact from themselves while they are perpendicular to the crack.

The amount of matrix reinforcement by fibers depends on the number of distributed cross-section directions: Parallel to the tensions, randomly in two dimensions, and randomly in three dimensions.

Usually in massive concreting, the fibers are in three-dimensional form and the increase in resistance can happen in all directions. For example, in roads and airports pavements, it is necessary to distribute fibers in two dimensions parallel to horizontal or strain tension axis. Finally, the fibers in one dimension are not effective.

1. Important factors in design and selection of fibers:

The important factors in the design of fibers are as follow: tensile strength, elasticity coefficient of fiber, separating problem in matrix-fiber, length of fiber, Possibility of transformation in concrete, Thickness of fibers surface, enlarging or bending their ends, Possibility to use multi-string fibers for better adhesion. The ultimate fiber reinforced concrete depends on this equation:

$$S_c = A S_m (1 - V_f) + B V_f \left(\frac{l}{d} \right)$$

Where:

S_c = Final strength of the cement paste.

V_f = Fiber volumetric ratio.

A = Constant Number.

B = Coefficient depending on the consistency resistance and shape of fibers.

1.1 Concrete with high stiffness:

The concrete with higher stiffness can tolerate many deformations without fail. The purposes of utilization of fibers in concrete increases tensile strength, cracks control, etc. In the fabrication of tunnels, the fiber concrete is used by spraying on the tunnel wall without armature to remove the crack in tunnel coverage.

In a new kind of fiber concrete can be reached high fineness with pouring slurries on the fibers. In this way the fibers are first shed then the spaces among them are filled with slurry mortar. The amount of fiber in this concrete is about 10%, which is about ten times the amount in conventional fiber concretes (10).

This type of material can create protective layers without crack. The compressive strength of this type of concrete is $85 \div 110$ Pascal and the bending strength is $35 \div 45$ N/m. These components can be used not only as small protective layers but also in the runways of airports, where it shows good performance against blows (10).

2. Construction Practices

2.1 Mixing: There are some important differences in mixing FRC compared to conventional concrete. One of these is the effect of fiber balling that prevents good dispersion of the fiber in concrete. There are two methods that have been effectively used in the past to prevent fiber balling of steel fiber:

- To add fibers to transit mix truck after all ingredients have been added and mixed.
- To add fiber to aggregate on a conveyor belt.

Using vibration is necessary for consolidating the concrete and, therefore, traditional slump cone test cannot be used for quality control. Although increasing the fiber amount could potentially improve the concrete properties (11).

2.2 Placing and finishing: According to literature, there are few differences between the methods for placing and finishing conventional concrete and FRC. A difference for slab construction is that vibration is needed for the FRC since the material tends to hang together. Additionally, high-range water-reducing admixtures should be added to FRC to increase the workability of the mixture and for easy placement (12).

2.3 Curing and protection: There is no special treatment when fibers are added to concrete. Like conventional concrete, FRC needs appropriate protection when placing during hot and cold weather (12).

3. Experimental Program by Khaloo:

Fourteen concrete mixtures with four different fiber contents, two different fiber lengths and two concrete strengths were designed. The slabs were square with dimensions of 820×820 mm and thickness of 80 mm. Four corners of slabs were seated on roller points which provided clear span length of 680 mm. Point load was applied by stroke mode of an actuator on $80 \times 80 \times 10$ mm steel plate placed at slab center. The displacement at the loading point was increased at rate of 1.5 mm/min. Sensitive linear voltage differential transducers were used to measure the deflection at slab center (13).

The compressive strengths of 152.4×304.8 mm cylindrical plain specimens were 30 and 45 MPa at the age of 28 days. The volumetric percentages of steel fibers, i.e., the ratios of the volume of fibers to the volume of matrix were 0.5, 1.0 and 1.5, which correspond to 25, 50 and 75 kg of steel fibers for mix proportions used in the tests.

Cement type I along with river aggregates was used. Sand had a fineness modulus of 2.7 and coarse aggregates had a maximum aggregate size of 19 mm. The superplasticizer corresponded with ASTM C494 Type F. The crimped shape steel fibers had a rectangular cross-section (13).

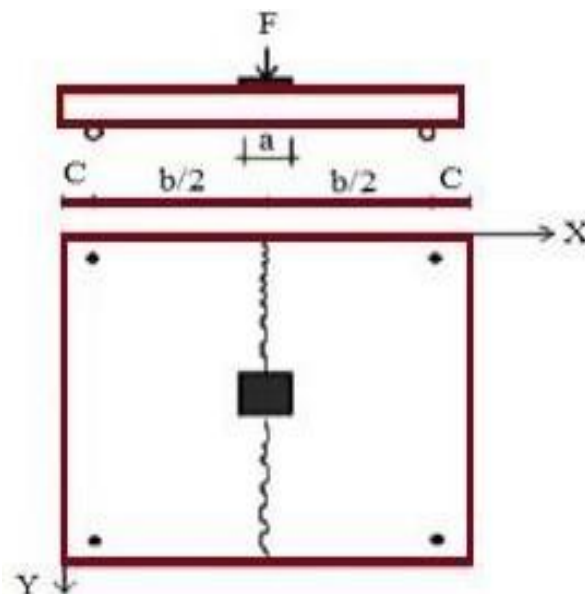


Fig 4. Slabs in the four corners of the square on the roller supports and load on the center of the slab (13). (A.R. Khaloo, M. Afshari / Cement & Concrete Composites 27 (2005) 141–149)

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The average test results for each pair of slabs are presented in Table 1 and also flexural test results of slabs are shown as load-deflection and absorbed energy-deflection curves in Fig. 5.

Table1. Experimental Program (13).

Concrete strength (f_c , MPa)	Fibre type	Fibre volumetric percentage	Specimen number	Number of cylindrical specimens	Number of slabs
30	-	0	1	3	2
		0.5	2	3	2
		1.0	3	3	2
	jc35	1.5	4	3	2
		0.5	5	3	2
		1.0	6	3	2
		1.5	7	3	2
45	-	0	8	3	2
		0.5	9	3	2
		1.0	10	3	2
	jc35	1.5	11	3	2
		0.5	12	3	2
		1.0	13	3	2
		1.5	14	3	2
Total number of specimens				42	28

(A.R. Khaloo, M. Afshari / Cement & Concrete Composites 27 (2005) 141–149)

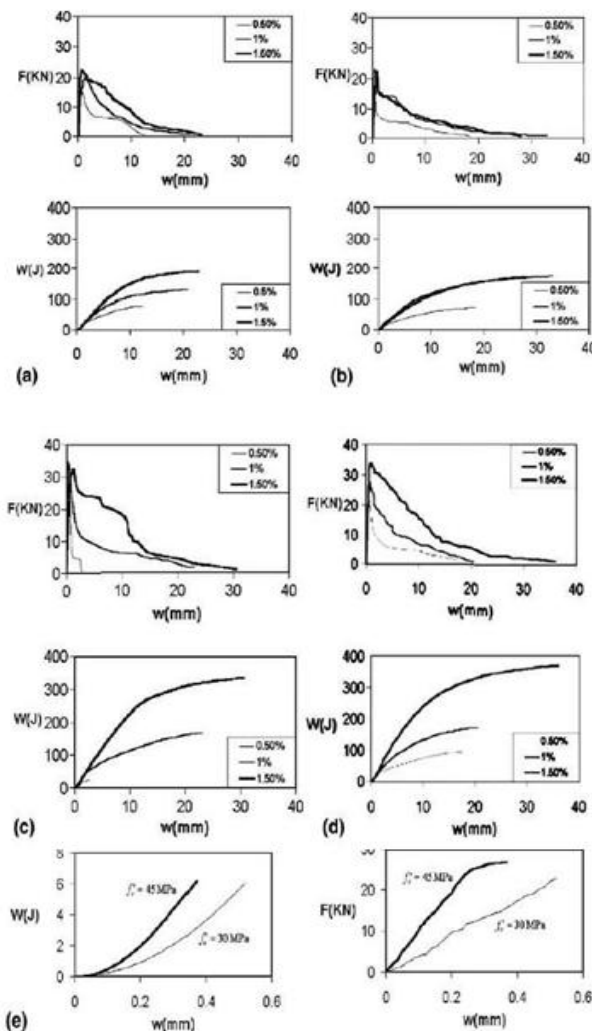


Fig 5. Load-deflection and absorbed energy- deflection curves for slabs. Concrete strength of (a) 30 MPa and jc25 fibers, (b) 30 MPa and jc35 fibers, (c) 45 MPa and jc25 fibers, (d) 45 MPa and jc35 fibers; and (e) plain concrete slabs (13). (A.R. Khaloo, M. Afshari / Cement & Concrete Composites 27 (2005) 141–149)

V. RESISTANCE DESIGN METHOD

Resistance design method, known as ultimate strength design of a component at each level should be equal or more than necessary the resistance, which is calculated by coefficients under load combinations (U):

$$(U) ResistanceRequired \leq DesignResistance$$

In this equation, the design resistance is calculated by multiplying resistance coefficient (ϕ) and nominal resistance.

$$Design Resistance = Resistance Coefficient \phi * Nomial Resistance$$

In these equations the resistance coefficient is lower than 1 that is considered for the compensation of the following issues:

- Probability of less resistance of a component based on possible variations used in the strength of materials and their dimensions.
- Inaccuracy in design equations.
- Importance of the component in the structures.

VI. FIBER CONCRETE DESIGN

This part is considered a review of the criteria and available regulations concerning analysis and design of fiber concrete. In this way the RILEM, FIB, and ACI regulations are investigated. The FIB and RILEM regulations are explained about flexural design discussion, shearing, and crack control in fiber concrete beams with and without armature, whereas from these two regulations FIB explains about the fiber concrete slab without armature only and it did not about component of fiber concrete and armature (14).

VII. DESIGN OF FIBER REINFORCED CONCRETE BEAMS IN RILEM REGULATION

RILEM is an international committee that is created by purposes of structural development and materials used in structures. In this regulation for fiber concrete design used to TC- 162-TDF RILEM. This regulation is used these equations to get concrete tensile stress and modulus of elasticity (15).

$$\begin{aligned} f_{ctm} &= 0.3f_c^3 \\ f_{ctk} &= 0.7f_{ctm} \\ f_{ct} &= 0.6f_{ct,fl} \\ f_{ct,fl} &= 0.7f_{ctm,fl} \end{aligned}$$

Where:

f_{ctm} : medium tensile strength of concrete.

f_{ck} : cylindrical compressive strength of concrete;

f_{ctk} : specification of concrete tensile strength.

f_{ct}, f_l : flexural strength of concrete;
 f_{ctm}, f_l : medium concrete flexural strength.

1. Determination of flexural tensile strength:

In this regulation, one of the important element in fiber concrete design is the flexural tensile strength ($f_{R,j}$). It should be used for displacement rate of crack opening experiment (CMOD), to determine this parameter according to the results of this trial, where f_{R1} and f_{R2} are calculated by this equation with substitution of $CMOD1$ and $CMOD4$ (15).

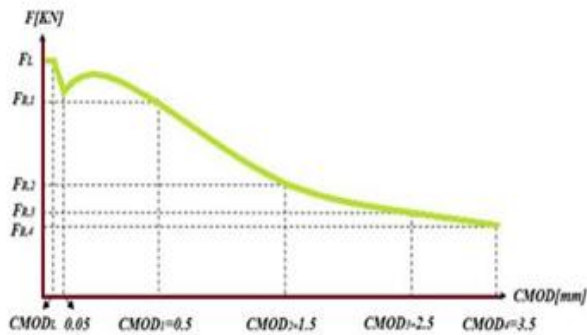


Fig 6. F-CMOD graph in TC-162-TDF RILEM regulation to determine flexural tensile strength (13). (A.R. Khaloo, M. Afshari / Cement & Concrete Composites 27 (2005) 141–149)

$$f_{R,j} = 3 \frac{f_j l}{2bh \frac{2}{sp}}$$

Where:

l : sample crater; b : sample width;
 h_{sp} : distance between gap top up to the sample tested;
 f_j : Corresponding load with $CMOD$;
 $f_{R,j}$: flexural tensile strength corresponding with $CMOD_j$ [$j=1, 2, 3, 4$].

Fiber concrete beams design without ordinary Armature
Design of fiber concrete beams without armature is similar to design of fiber concrete with armature with this difference that armature has been deleted (15).

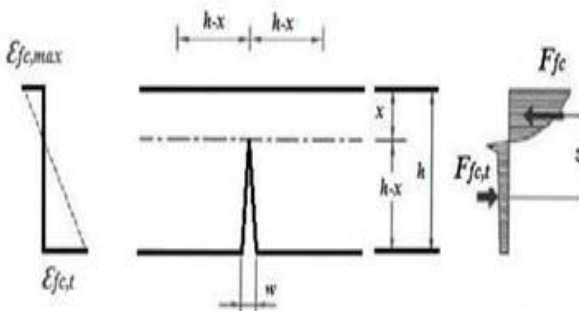


Fig 7. Fiber concrete stress-strain diagram without armature in RILEM TC-162-TDF (15). (Journal of Material and Structures. 2003)

2. Shear Capacity in RILEM Regulation:

The shear capacity in RILEM is calculated by the sum of concrete shear strength, shear reinforcement of the armature, and fiber shear strength (15).

$$V_{Rd} = V_{cd} + V_{fd} + V_{wd}$$

$$V_{Rd} = [0.12k(100\rho_1 f_{ck})^{3/4} + 0.15\sigma_{cp}]bd$$

Where:

σ_{cp} : average stress on concrete due to loading;
 ρ_1 : armature percentage.

$$\rho_1 = \frac{A_s}{bd} \leq 2\%$$

$$\sigma_{cp} = \frac{N_{sd}}{A_c}$$

Where:

N_{sd} : Axial force in the form of pre-stress
 $\sigma_{cp} = 0$,

In the absence of axial force in this section

$$V_{fd} = 0.7 K_f K_{rfd} bd$$

$$K_f = 1 + n \left(\frac{h_f}{b_w} \right) \left(\frac{h_f}{d} \right), K_f \leq 1.5$$

$$r_{fd} = 0.12 f_{Rk,4}$$

$$V_{wd} = \frac{A_{sw}}{s} 0.9 d f_{ywd} (1 + \cot \alpha) \sin \alpha$$

$$n = \frac{b_f - b_w}{h_f} \leq 3, n \leq \frac{3b_w}{h_f}$$

Where:

s : distance between shears armature;
 α : shear armature angle;
 f_{ywd} : Surrender Resistance of armature shear reinforcement
 A_{sw} : Shear armature area

3. Calculation of crack width:

$$\varepsilon_{sm} = \frac{\sigma_s}{E_s} \left[1 - \frac{\beta_1}{\beta_2(\sigma_s)} \right]$$

For considering fiber effect in calculation of crack width, the RILEM regulation changed the S_{rm} data in formula and with multiplying by $(50df/I_f)$, this regulation changed this formula with the maximum amount:

$$S_{rm} = (50 + 0.25K_1 K_2 \frac{\phi_b}{\rho_r}) \left(\frac{50}{\phi} \right)$$

The important note in the above equation is that the amount of fiber is not indicated and the effect of fiber changing on crack width, is too less. The main weakness of this model to predict the average cracks is that the amount of fiber is not considered. Crack distance modified model is recommended by Moffatt (2001) and has been developed in Eurocode 2 (15):

$$S_{rm} = (50 + 0.25K_1K_2 \frac{d_b}{\rho_{eff}})(1 - \frac{f_{res}}{f_{cr}})$$

4. Fiber crack width calculation without armature in RILEM:

$$W = \epsilon_{fc,t}(h-x)$$

$$\epsilon_{fc,t} = \epsilon_{fc,max} \frac{(h-x)}{x}$$

Where:

$\epsilon_{fc,max}$: Concrete pressure strain

$\epsilon_{fc,t}$: Concrete tensile strain

Crack width calculation without armature indicated that in the final, the crack width is more than allowed amount. So, it requires a high percentage of fibers (15).

VIII. BENDING STRENGTH

The well-known design model for steel reinforced concrete with the design at the cross section will be extended with an additional tension force for the calculation of the load carrying capacity of flexural strengthened slabs (16).

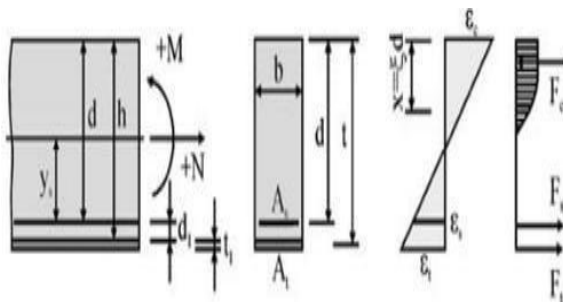


Fig 8. Internal forces and strains on the cross section (16).
(Materials and Structures (2006) 39:741–748)

During the test, the deformation on the web side of the RC-member was measured by a displacement transducer at several points.

At each measuring point the deformations in three directions were documented: those towards the textile reinforcement, those towards the steel stirrups and those towards the concrete struts. In addition, the deflection of the specimen and the crack pattern on the web side were recorded (16).

IX. ABAQUS

The behavior of concrete is nonlinear and complex. Increasing use of computer-based methods for designing and simulation has also increased the urge for the exact solution of the problems. This leads to difficulties in simulation and modeling of concrete structures. A good approach is to use general purpose finite element software like e.g. ABAQUS. In this paper a 3D model of a concrete

cube is prepared using smeared crack model and concrete damage plasticity approach.

The validation of the model to the desired behavior under monotonic loading is then discussed. This paper used the ABAQUS software for development of numerical model.

The limitations of this software for fiber concrete modeling were randomly. To solve this problem, it was used MATLAB to create the required number of fibers. Then enter the program that is written by MATLAB in ABAQUS software. Eventually, the desired fibers will make (17).

1. ABAQUS damaged plasticity model:

Out of the three concrete crack models, the concrete damaged plasticity model is selected in the present study as this technique has the potential to represent complete inelastic behavior of concrete, both in tension and compression, including damage characteristics.

Further, this is the only model, which can be used both in ABAQUS/Standard and ABAQUS/Explicit and thus enable the transfer of results between the two. Therefore, the development of a proper damage simulation model using the concrete damaged plasticity model will be useful for the analysis of reinforced concrete structures under any loading combinations including both static and dynamic loading (18).

The concrete damaged plasticity model assumes that the two main failure mechanisms in concrete are the tensile cracking and the compressive crushing. In this model, the uniaxial tensile and compressive behavior is characterized by damaged plasticity. The Concrete Damaged Plasticity (CDP) model used in the ABAQUS software is a modification of the Drucker-Prager strength hypothesis.

In recent years the latter has been further modified by Lubliner, Lee and Fenves. According to the modifications, the failure surface in the deviatoric cross section needs not to be a circle and it is governed by parameter kc (19).

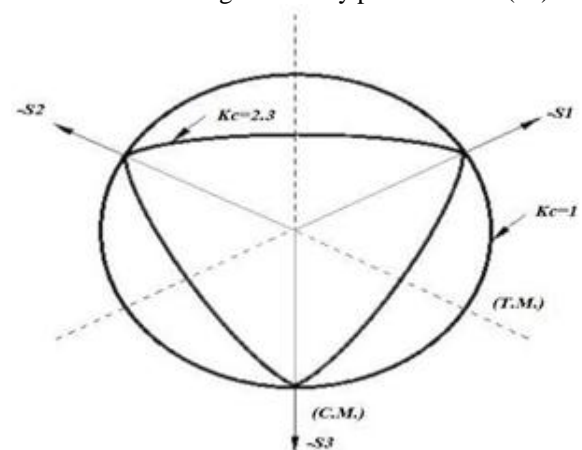


Fig 9. Deviatoric cross section of failure surface in CDP model (19). (Kmieciak P, Kamiński M. 2011)

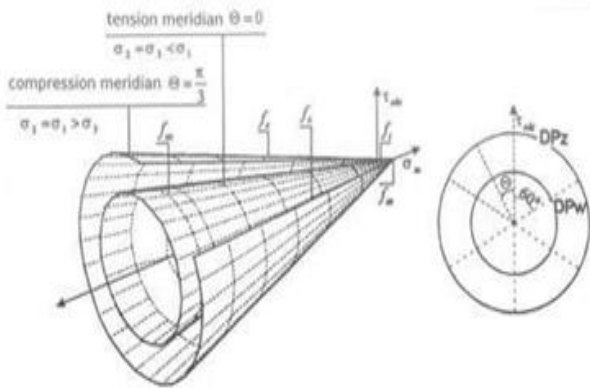


Fig 10. Drucker–Prager boundary surface 0: a) view, b) deviatoric cross section (19). (Kmieciak P, Kamiński M. 2011)

Physically, parameter K_c is interpreted as a ratio of the distances between the hydrostatic axis and, respectively, the compression meridian and the tension meridian in the deviatoric cross section. This ratio is always higher than 0.5 and when it assumes the value of 1, the deviatoric cross section of the failure surface becomes a circle (as in the classic Drucker–Prager strength hypothesis). The CDP model recommends assuming $K_c = 2/3$. This shape (Fig 9) is similar to the strength criterion (a combination of three mutually tangent ellipses) formulated by William and Warnke in 1975. It is a theoretical- experimental criterion based on triaxial stress test results (19).

In the CDP model the plastic potential surface in the meridional plane assumes the form of a hyperbole (Fig.11). The shape is adjusted through eccentricity (plastic potential eccentricity). It is a small positive value which expresses the rate of approach of the plastic potential hyperbola to its asymptote. In other words, it is the length (measured along the hydrostatic axis) of the segment between the vertex of the hyperbole and the intersection of the asymptotes of this hyperbole (the Centre of the hyperbole).

Parameter eccentricity can be calculated as a ratio of tensile strength to compressive strength (20).

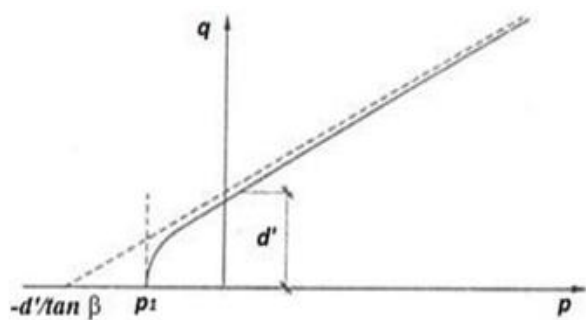


Fig 11. Hyperbolic surface of plastic potential in meridional plane (19). (Kmieciak P, Kamiński M. 2011)

Another parameter describing the state of the material that is the point in which the concrete undergoes failure under biaxial compression.

σ_{b0}/σ_{c0} (f_{b0}/f_{c0}) is a ratio between the strength in the biaxial and the uniaxial state (Fig.12). The most reliable in this regard are the experimental results reported by Kupler in 1969. After their approximation with the elliptic equation, uniform biaxial compression strength f_{cc} is equal to $1.16248f_c$.

The ABAQUS user's manual specifies default $\sigma_{b0}/\sigma_{c0} = 1.16$. The last parameter characterizing the performance of concrete under compound stress is the angle of inclination of the failure surface towards the hydrostatic axis, measured in the meridional plane (dilation angle). Physically, dilation angle Ψ is interpreted as a concrete internal friction angle.

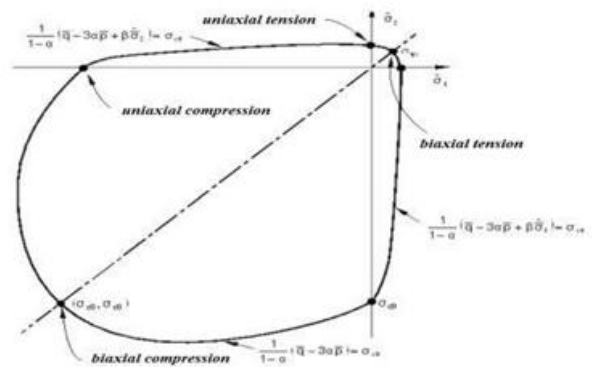


Fig 12. Strength of concrete under biaxial stress in CDP model (19). (Kmieciak P, Kamiński M. 2011)

2. Stress-Strain curve for uniaxial tension:

The tensile strength of concrete under uniaxial stress is seldom determined through a direct tension test because of the difficulties involved in its execution and the large scatter of the results. Indirect methods, such as sample splitting or beam bending, tend to be used (21).

$$f_{ctm} = 0.3f_{ck}^{\frac{2}{3}}$$

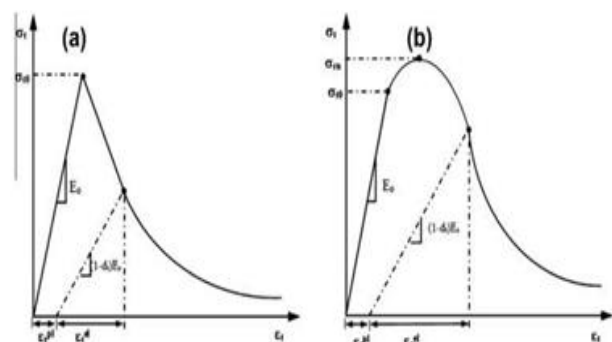


Fig 13. Uniaxial stress-strain curve with damage in tension (a) and compression (b)(19). (Kmieciak P, Kamiński M. 2011)

According to the ABAQUS user's manual, stress can be linearly reduced to zero, starting from the moment of reaching the tensile strength for the total strain ten times higher than at the moment of reaching f_{ctm} . But to accurately describe this function the model needs to be calibrated with the results predicted for a specific analyzed case. The proper relation was proposed by, among others, Wang and Hsu (22).

$$\sigma_c = E_{cet} \text{ if } \varepsilon_t \leq \varepsilon_{cr}$$

$$\sigma_t = f_{cm} \left(\frac{\varepsilon_{cr}}{\varepsilon_t} \right)^{0.4} \text{ if } \varepsilon_t > \varepsilon_{cr}$$

Where ε_{cr} stands for strain at concrete cracking. Since tension stiffening may considerably affect the results of the analysis and the relation needs calibrating for a given simulation, it is proposed to use the modified Wang & Hsu formula for the weakening function.

$$\sigma_t = f_{cm} \left(\frac{\varepsilon_{cr}}{\varepsilon_t} \right)^n \text{ if } \varepsilon_t > \varepsilon_{cr}$$

Where n represents the rate of weakening.

Here used to Nayal and Rasheed model to determine Stress-Strain diagram form. In this model, to avoid runtime error in ABAQUS software, there is a decrease in resistance to $0.8 \sigma_t$. To get the maximum tensile stress, if laboratory results are not available (cylinder fissure testing or direct stretching), it is possible to use (4-23) equation (23).

$$\sigma_t = 0.3 \sigma_c^{\frac{2}{3}}$$

Failure parameter (d_t) is equal to the ratio between Strain failure (ε_{ck}) and General strain (ε_t): 0 for healthy materials and 1 for unhealthy materials. According to Fig 14, the accuracy of results increases with strain during loading (23).

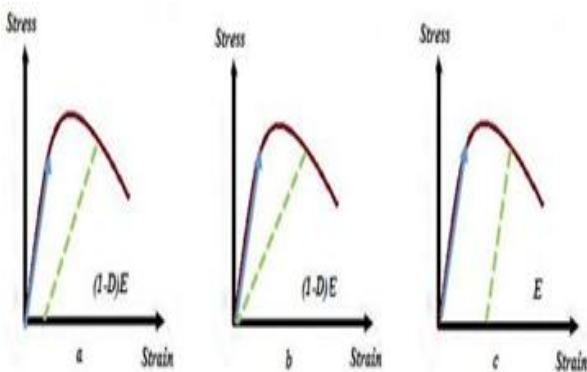


Fig 14. Loading behavior - Concrete handling a) Experimental, b) Plastic damage model regardless of failure parameter, c) Plastic damage model in terms

offailureparameter (23). (Nayal R, Rasheed HA, Journal of Materials in Civil Engineering, 2006)

X. MESH DEPENDENCY

In continuum mechanics, the constitutive model is normally expressed in terms of stress-strain relations. When the material exhibits strain-softening behavior, leading to strain localization, this formulation results in a strong mesh dependency of the finite element results, where the energy dissipated decreases upon mesh refinement. To illustrate the problem let us consider a bar subjected to uniaxial tension (Fig. 15) (24).

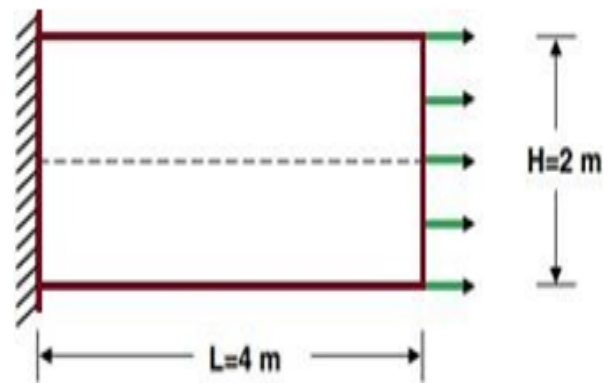


Fig 15. Bar subjected to axial load (24). (Lapczyk, J.A. Hurtado / Composites: Part A 38, 2007)

The bar consists of a material that is linearly elastic until a peak value of stress is reached and softens linearly in the post-peak regime (Fig. 16) (24).

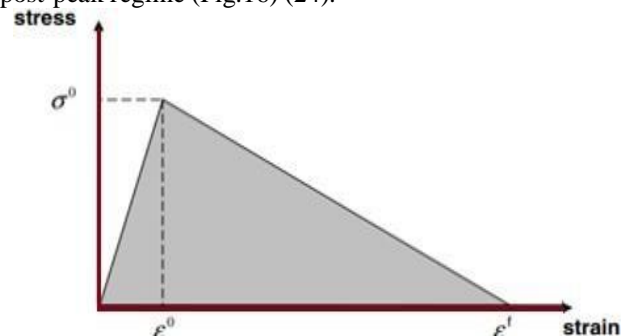


Fig 16. Stress versus strain diagram for a linearly softening material (24). (Lapczyk, J.A. Hurtado / Composites: Part A 38, 2007)

XI. MESHING

For concrete modeling are used 8D-3C elements, with approximately 30 mm dimension like (Fig. 17) and for steel fiber modeling 2D-3T element with approximately 10 mm dimensions. The fiber is bonded to concrete with Embedded Regions technique.

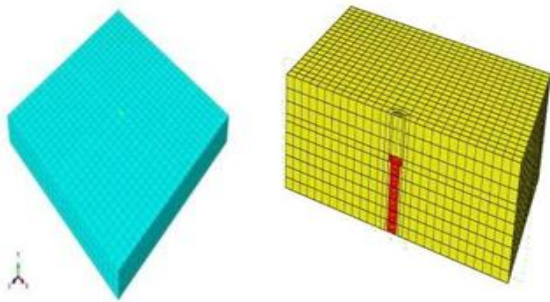


Fig 17. Fiber Concrete Slab Meshing in ABAQUS (25).
(Yuhong Ling, International Journal of Steel Structures, 2019)

XII. SLAB FAILURE MODE

According to Fig.18 and 19, the laboratory failure mode is creating a rupture from the middle of the slab to both sides.

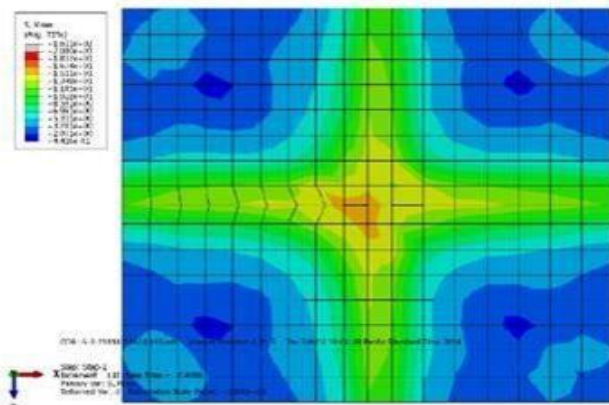


Fig 18. Concrete Tension Distribution of Fiber Concrete Slab.

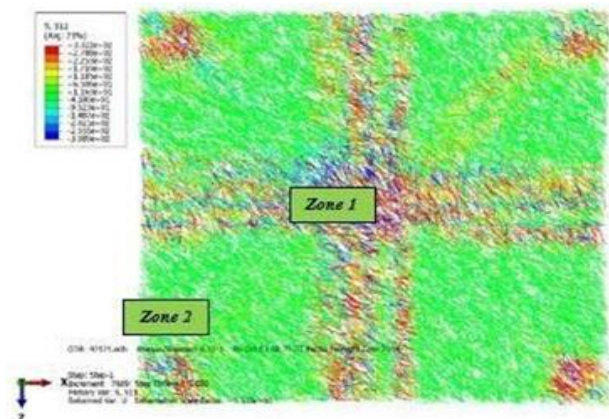


Fig 19. Distribution of steel fiber tension in Fiber Concrete Slab.

XIII. STEEL FIBER STRESS-STRAIN GRAPH IN FIBER CONCRETE SLAB

According to Fig.19, the fibers that were in the direction of concrete failure, have more stresses rather than other fibers. As the Fig.20 shows, the fibers in the central area

of the slab have reached their elastic limits and entered to the plastic area. As Fig.21 shows, the fibers are in the plastic area.

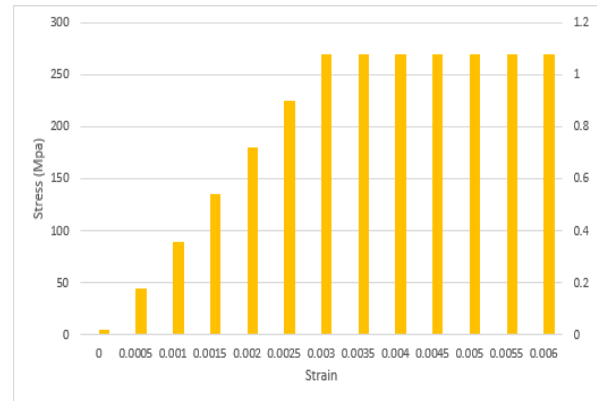


Fig 20. Strain-Stress graph, A sample of steel fibers in area1.

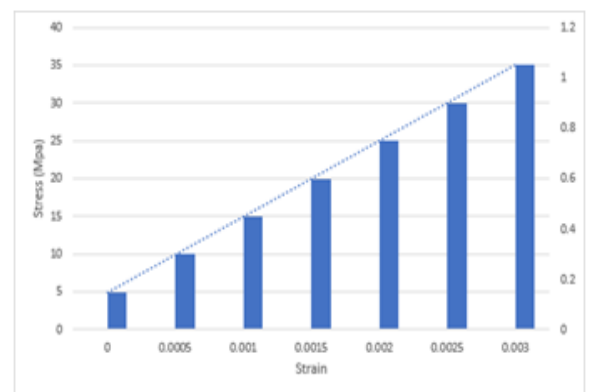


Fig21.Strain-Stress graph, a sample of steel fiber in area2. According to the results of numerical analysis of fiber concrete slab, available laboratory results and differences between these due to distension of fibers in laboratory work, the results of numerical analysis were globally satisfactory.

They can be used as numerical model of the slab in railroad applications with behavioral models of concrete and fiber in the validation model.

XIV. RAIL SLAB LINE ANALYSIS, FLEXURAL AND SHEAR FORCES

1. Characteristics of the slab line and introduction of applied loads

The scope is the investigation of a typical slab line on the soil bed. In order to provide proper operation conditions and high safety, it is necessary to consider criteria and assumptions of non-ballasted line system.

Generally, the pavement system must meet the following requirements:

- Tolerate the operation loads in common operation and design speed.
- Resist to dynamic effects and impacts caused by train movement.
- Maintain its integrity without getting ruptures due to inner forces created by differential loading.

2. Loading:

Loads on the pavement include:

2.1 Dead Load: it includes loads that are relatively constant over time, including the weight of the structure itself and fixtures such as walls, plasterboard, or carpet. The roof is also a dead load. Dead loads are also known as permanent or static loads. Building materials are not dead loads until constructed in permanent position. The dead loads on the pavements include, bearing and non- load bearing components (26).

Here the dead loads include slab, rail and sleepers. The consumable concrete specific weight is 2500 kg/m³ and rail unit weight is 60 kg/m. It should be noted that the recommended amount in Eurocode regulation is 25 for reinforced concrete specific weight.

2.2 Live Load: It includes important components in each structural design combination. This information is determined based on available statistics, measurements, behavioral distributions, structural analysis and probability theory. Live Load pattern has an important role in the design of the slab line and different regulations have recommended patterns for it, depending on the type of operation: passing vehicles, traffic volume, speed, maintenance conditions, different in various countries. In rail transport there are similarities in the loading pattern due to a smaller variety of vehicles and machinery. AREMA regulation recommended LM71 for traffic load modeling (27).

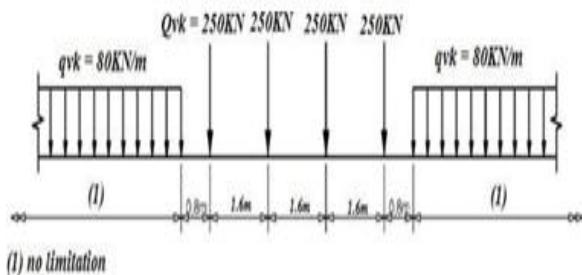


Fig 22. LM71 Loading Model (27). (M. Esmaili et al./ Soils and Foundations 58 (2018) 319–332)

XV. MODELING

The concrete pavement modeling has done in 3D and using SAP2000 software. In Fig.23 the three- dimensional view is represented.

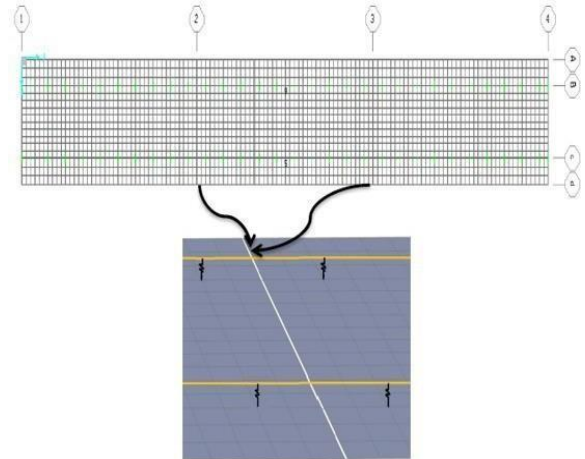


Fig 23. Concrete pavement modeling in 3D using SAP2000

The original model simulated three slabs with 6- meter length and 2 cm as seam between the slabs. According to Fig.23, the line modeling of the rail to rail distance is 1.5 m that include concrete slab done by Shell-Thick element.

It is considered 18 m for the length and 260 cm for the width. Axis to axis distance is considered 150 cm. After applying the hit coefficients, the moving load, moves on the rails in two lanes.

The rail connection to the concrete slab has done in 60 cm distance with use of LINK element, a type of linear spring, which in the axial direction includes 450 kN/mm hardness. This hardness is equal to the pad hardness under the rail and is free in the other directions (28). The level under the slab is identified in the software, in terms of spring areas: 1) Soft = 5000, 2) Medium = 20000, 3) Hard = 100000.

XVI. ANALYSIS OF RESULTS: DETERMINATION OF SHEAR AND BENDING FORCES ON SLAB LINE

According to the results, with increasing of bed reaction coefficient, the longitudinal, transversal and shear moments on slab lines will decrease a lot.

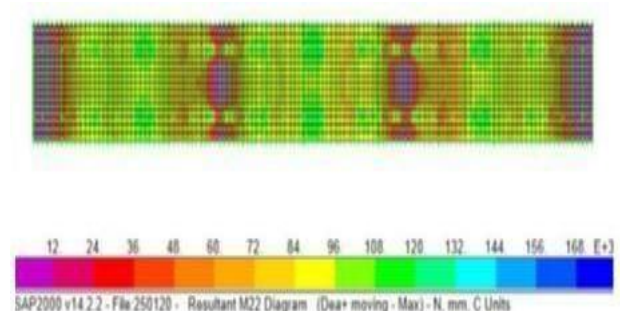


Fig 24. Max longitudinal moment in combination of 1.35DL+1.5LL loads.

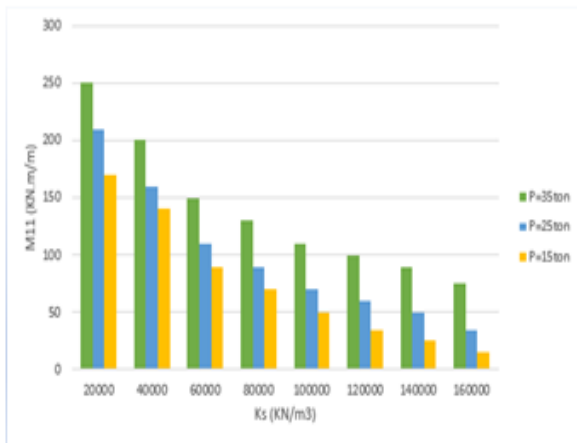


Fig 25. Results of transversal anchor, the axial load changing and bed reaction coefficient in constant speed $V = 120 \text{ Km/h}$.

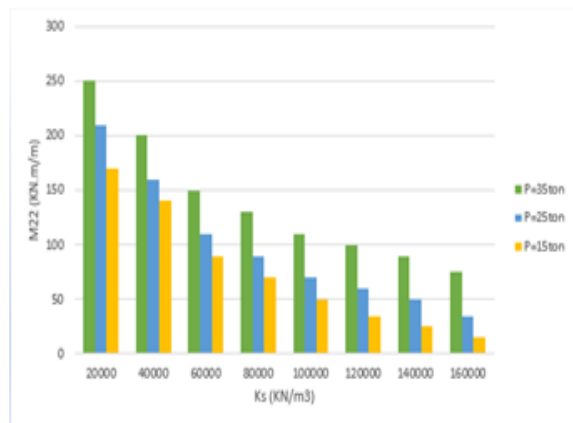


Fig 26. Results of longitudinal anchor, the axial load changing and bed reaction coefficient in constant speed $V = 120 \text{ Km/h}$.

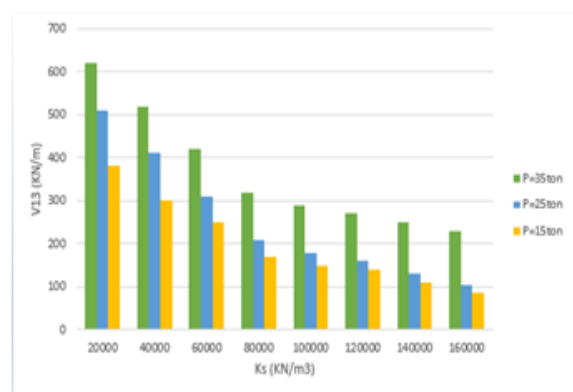


Fig 27. Results of transversal cutting, the axial load changing and bed reaction coefficient in constant speed $V = 120 \text{ Km/h}$.

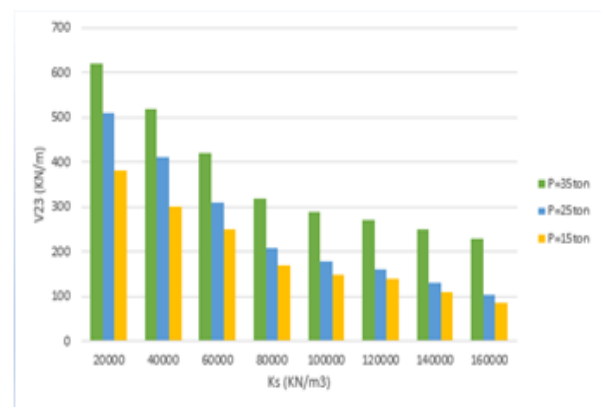


Fig 28. Results of longitudinal cutting, the axial load changing and bed reaction coefficient in constant speed $V = 120 \text{ Km/h}$.

After the analysis, results of shear forces and bending anchors are extracted and the design work can start.

1. How to save time and money:

To eliminate completely steel fiber reinforcement, saving both materials and labor:

- Reduce slab thickness giving savings in concrete and placement costs.
- Make possible wider joint spacing, by saving joint forming costs and maintenance.
- Simplify the construction: simpler joints and no longer errors in steel fabric positioning.
- Increase speed of construction.

2. Technical and user benefits:

- Significantly reduced risk of cracking.
- Reduced spalling joint edges.
- Stronger joints.
- High impact resistance.
- Greater fatigue endurance.
- Reduced maintenance costs.
- Longer useful working life.

3. Advantages:

- Reinforcing concrete with steel fibers results in durable concrete with high flexural and fatigue flexural strength, improved abrasion, and spalling and impact resistance.
- The elimination of conventional reinforcement and, in some cases, the reduction in section thickness can contribute to some significant productivity improvements. Steel fibers can deliver significant cost savings, together with reduced material volume, more rapid construction and reduced labor costs.
- The random distribution of steel fibers in concrete ensures that crack free stress accommodation occurs throughout the concrete. Thus, micro cracks are intercepted before they develop and impair the performance of the concrete.

- Steel fibers are a far more economical design alternative.

4. Disadvantages:

- Steel fibers will not float on the surface of a properly finished slab; however, rain damaged slabs allow both aggregate and fibers to be exposed and will present as aesthetically poor whilst maintaining structural soundness.
- Fibers are capable to substitute reinforcement in all structural elements (including primary reinforcement), however, within each element, there will be a point where the fibers alternative's cost saving, and design economies are diminished.
- Strict control of concrete wastage must be monitored in order to keep it at a minimum. Wasted concrete means wasted fibers.

XVII. CONCLUSIONS

With increasing of hardness under the concrete slab, the amount of incoming force to the slab will decrease. E.g. with 25 t axial load, 120 km/h speed, and change in hardness from 5000 to 20000 and 100000 kN/m³, the amount of incoming longitudinal anchor, increased to 46% and 68%, while the amount of armature is reduced.

Economically, the cost of utilization of fiber with armature is more than usage of armature in alone situation. E.g. with 25 t axial load, 120 km/h speed and 20000 kN/m³ hardness, the amount of required fibers with 0.25, 0.5, 0.75 volumetric percentages the cost of building of the slab lines increase respectively by 9.5%, 21% and 33%.

By adding fiber to concrete slab, the amount of required armature reduced slightly, and the crack width greatly decreased. E.g., with 25 t axial load, 120 km/h speed, and 20000 kN/m³ hardness, the number of required fibers with 0.25, 0.5, 0.75 volumetric percentages cause the decrease of the amount of armature to 3.5%, 4.9% and 6.3% and the crack width decreased respectively to 26%, 30% and 35%. Utilization of fiber alone in concrete slab line does not have required bending strength to tolerate the incoming loads. On the other hand, in this condition the crack width is several times larger than allowed cracks in regulation. According to the results, it can be concluded that a high percentage of fibers are required. Therefore, this work is not affordable.

The service's loading results in concrete with and without fiber indicate that increasing fiber does not have many impacts in shear forces and bending anchors. As a result, it is possible to use a concrete slab without fiber for analyzing the fiber concrete slab and designing it.

According to the results obtained from flexural and shear design, it can be concluded that the shear strength due to longitudinal armatures and fibers due to shear forces are

from analysis of the slab line due to dynamic crossing loads that an increase of incoming bending forces and the shear design is not a criterion.

Among all kinds of fibers which can be used as concrete reinforcement, steel fibers are the most popular ones. The performance of the Steel Fiber Reinforced Concrete (SFRC) has shown a significant improvement in flexural strength and overall toughness compared against conventional reinforced concrete.

The behavior of uncracked concrete and concrete between cracks was simulated under the Elastoplast city framework. The soil or other base material, supporting the concrete slab was simulated by distributed springs orthogonal to the concrete slab middle surface. An elastic-plastic model was used to modulate the non-linear behavior of the springs. The loss of contact between the base and the slab was accounted for.

Mechanical properties are improved by the incorporation of steel fibers in UHSC especially splitting tensile strength. Steel fibers increased the total charge passing and the electrical conductivity of the concrete and the increase depends on the volume fraction of the steel fibers.

In slabs with low fiber volume (0.5%) the resisting load after cracking was relatively small. The rate of improvement in energy absorption reduced with the increase in fiber content. The compressive strength of high strength, lightweight concrete was only slightly improved with the addition of steel fiber. The tensile/compressive strength ratio was obviously enhanced. These were attributed to the effect of the steel fiber arresting cracking.

Use of fiber produces more closely spaced cracks and reduces crack width. Fibers bridge cracks to resist deformation. Fiber addition improves ductility of concrete and its post-cracking load-carrying capacity. The mechanical properties of FRC are much improved by the use of hooked fibers than straight fibers, the optimum volume content being 1.5%. While fibers addition does not increase the compressive strength, the use of 1.5% fiber increases the flexure strength by 67%, the splitting tensile strength by 57% and the impact strength 25 times.

The properties like shear, torsion and bending are also improved due to addition of fibers in the concrete. This is obvious because the addition of fibers resists the development of internal micro crack in the concrete, which are responsible for the failure of the structure.

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