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Strengthening concrete slabs rest on soil grade using steel fibers

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Abstract

Concrete slabs are the most construction members which is in touch with soil. The applied load on concrete slab causes a deformation in slab and soil which making a relative movement between the two medias and that's what named by soil-structure interaction. Improving concrete slab strength allows the designer to get the required strength without increasing slab thickness and necessary for safety purposes when the slab exposed to unexpected loads. The study investigated this interaction by casting three concrete slabs and applied a static load on them to discuss their behavior and the soil response. Three plain square slabs of 600 mm sides and 40 mm thickness were casted and tested to investigate the concrete enhancement. The first slab is conventional while the second was of 0.5% percentage of steel fiber and the third specimen was of 1% of steel fiber. It was concluded that, the center of slab deflects downward, while the corners go upward then settles. Adding Steel fiber enhance the concrete compressive strength. The development in slabs bearing capacity were enhanced by 44.7% and 67.03% after adding 0.5% and 1% of fibers respectively.

Keywords: *Slab, Foundation, Soil, Soil-Structure interaction, Steel Fiber*

1. Introduction

Usually, all the civil construction rest on ground, whether the ground was soil or rocks, and whether it is resting directly by the foundation or transfer the load into the rock layers by piles. It is necessary to build a stiff portion which can relocate the building load into the ground like a base for the construction. Often this stiff portion is a rigid concrete slab, which is designed to provide a deposit support reliant on its stiffness and soil bearing capacity [1].

Concrete slabs are straight, plane, two-dimensional structural member. The third dimension is the slab thickness (h) which is usually much less than the other two dimensions. slab is unlike their counterparts (columns, beams, etc.…), it can be considered as a complete structure just like machine foundation. It can be supported by different ways, like: simply supported, fixed, includes elastic support, or even point supports like flat plate holding by columns. Usually, slabs on elastic foundation are subjected to static loads in addition to dynamic loads. They predominantly affect vertically to the surface of plate. Slabs resist these loads by internal bending, torsional member and transverse shear forces. Many civil structures can be classified as plates, like: floors, slab foundation, rigid pavement, warehouse floors, thin retaining walls, slab bridges, and bridge decks. Plates could have uniform or variable thickness, also, it may casted in arch shapes [2].

ACI-360 committee defines slab on grade, which is continuously supported by soil and totally loading when uniformly distributed, it is the member which impart pressure to the ground by less than 50% of the allowable bearing capacity thereof [3]. Concrete plates (slabs), which are upheld by a soil medium, is a widely used form of constructions because of their: durability, mastery to overcome subgrade weakness, and power to resist hard climate conditions. Such type of constructions usually exposed to non-uniformly distributed loads. That load will develop stresses and leading to slab failure. In addition, slab-on- grade may failed more quickly if the cavities and excavations form below it. A mat foundation is another face of slab-on-elastic foundation. It is usually subjected to a high amount of load from multi-story building columns [1].

Loads (dead or live loads) normally work on re-distribution and densification of soil particles. So that it is important to compact the soil before construction to avoid soil settlement or, at least, to minimize it within the allowable limits. Knowing that, the risks of total settlement are less than the risks of differential settlement because the total settlement is a settling in the whole structure but the differential is settling in a part of it, which will cause huge cracks in the walls till the cracks reach to the building's slab [1].

Another three additional difficulties in soil action have to be mentioned. First, the soil is a soft material. Such materials, usually, are complex to extract undisturbed samples for it for the laboratory tests. Second, the soil material properties are stress dependent, which means, its properties routinely change with stress existence and absence. Third, the soil actually consists of many horizontal layers. Each layer has properties may be completely differ from the neighboring layers. As a result, it is hard to obtain a clear and exact information about the soil. Consequently, designers will be forced compulsion to make some assumption in order to deal with it [1].

Commonly, the slab supports by nature ground surface, or sub-base layer (if the soil is weak or expansive like peat and clay and if the soil was too loss, a prestress slab may be used). These necessary layers are consisting of rocks or course gravel. Such layers, after compacting it, will be working on providing a uniform support for the concrete slab and avoiding water to altitude by the capillary rise to the concrete slab. The peril of water rise is hidden in the corrosion of the reinforcement of the slab. So that, codes call for increasing covers in the members which is in contact with soils for more safety. Another advantage of these layers is that, the sub-base layers protect the concrete from sulfate attack. This base layer has to be stiff enough because, and in accordance to some measurements done in Chile and Guatemala cities, the slab is always curled and its edges go upward without warping. But stiffer base layer, leads to a little slab sinking into the soil, and therefore small curling occurs. This curling occurs because of hydraulic and thermal gradients during the construction process [4].

Abd-Ali [5] experimental and numerical ((ANSYS) program) studies were discussed for concrete slab supported by soil media. The slab was square with 600 mm sides and 40 mm thickness. The reinforcement specimens were providing by 4mm at 65 mm spacing mesh. The research involved many parameters condition such as: slab thickness, load eccentricity, presence of reinforcement, and bearing load plate shape. The results showed the following, increasing in slab thickness by 50 % will increase the value of the applied ultimate load by 56 % and decrease the deflection by 55 %. Also, square loading plate gives an ultimate load greater than the circular loading plate by 45.45 %. When the load is applied as an eccentric distance, will decrease the ultimate applied load by 49.05 %. The presence of rebars in concrete slab increase the ultimate load and decrease the deflection at middle and corner of the slab.

Alani et al [6] introduced an experimental and numerical studies to investigate the behavior of ground supported slab. The experimental work involved testing a concrete slab of (6000*6000*150 mm) of 20MPa compressive strength and of 0.001 steel fiber ratio. The slab lies on the natural ground level and tested by applying concentrated loads at slab center. The numerical model simulated the experimental slab by finite element program (ANSYS 12.1). The soil has been represented as a one – parameter model (i.e. Winkler model). This model symbolized the soil as a group of springs with specified modulus of subgrade reaction K (N/mm^3). After analysis, a good agreement obtained from the experimental and numerical results. The numerical results showed that the increment in soil modulus of resilience, increases the rate of slab deflection and minimized the overall slab deflection.

Cajka et al [7] experimental and numerical study investigated the foundation slab interaction with subsoil media. A plain square concrete slab of 500 mm sides and 48mm thickness was casted and exposed to point vertical load of a loaded area equals (200*200mm). The slab rests on a loss loam soil of elastic modulus equals 2.65MPa and Poisson's ratio equals 0.35. Fig.1 explain the slab during the test. The slab failed at 18.6kN with 4 mm deflection. The concrete slab simulated as (2D) in the Nexis32 software, while the soil was considered as elastic deformable model. From the results, the FEM non-linear methods were the perfect way to solve the mentioned task. The iteration analysis method has been used. The program solves the system after approximately 7-8 iteration steps.

Strengthening concrete slabs could be found in machine foundations, spread footings and runways. Strengthening concrete slabs is an essential topic to be study which is working on enhancing the bearing capacity of each foundation in touch with soil grade. Strengthening slabs generally done for voiding the unexpected loadings and necessary for regions that forms cavities in here soil, just like Al-Najaf soil which contains a wide amount of gypsum which dissolve while raining leaving cavities with different sizes and shapes as discussed previously by Attiya et al [8–10].

Fig. 1: Testing view and failure model.

2. Experimental program

2.1. Determination of specimens dimensions

In order to understand the behavior of a concrete slab rests on an elastic media, as well as a slab rests on a voided soil, models of concrete slabs were casted in order to make an exactly simulation to the real problem. Slabs were molded in dimensions of 600×600×40 mm. On the other hand, the elastic theory method [11] shows that, the applied stresses on a soil media spreads vertically, horizontally, and laterally in z-direction. In this research, and according to this theory, a wooden box of dimension 1500×1500×1300 mm was used for containing a sandy soil. The concrete slab is placed on the top surface of the soil. As the elastic theory suggests, the load which is transferred vertically to the soil from square footing equals 7% of the total applied load at depth of 2B (where B is the footing width). According to this suggestion, the height of the wooden box container should not be less than 1200 mm, but an additional edge of 100mm was added to the container height to maintain the soil from falling during the experimental works achieving. While for the two other dimensions, 2.5B was used.

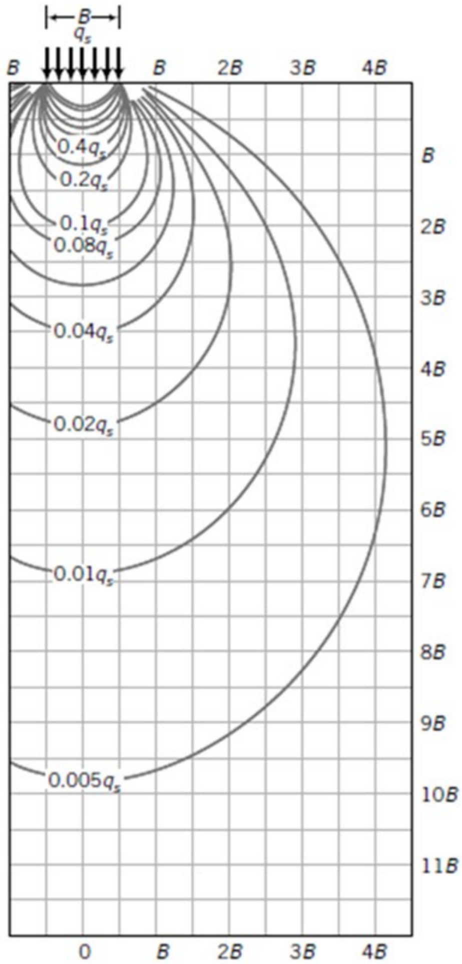

Fig. 2: Vertical stresses contour below a square foundation [11].

2.2. Manufacture of testing system

The testing system, overall consists of two main parts, the first part consists of steel frame, hydraulic jack press system and beams which are carried the dial-gages, and the second part is the soil container. Casting a reinforced concrete slab, as a base for the soil wooden container. The columns of the frame were fixed within the floor slab and extent below the ground level for a 700mm depth. This concrete slab was cured after drying by spreading water into it two times a day and along 28 days before putting the wooden box on it in order to improve its capacity as shown in Fig.3.

To apply the load on the slab, a hydraulic press jack with 20Ton capacity was used. It consists of three pieces. They are the press member, pump member and gage load counter. When pumping, the hydraulic pressure moves from the pump member to press member through a hose-pipe. Also, the press member includes an adjustable rotary ring, which is used to tweak the hunger arm, where welding is Forbidden to avoid the thermal damage of the oil inside the jack (the details are explained in Fig.4.). Fig.5 shows the hydraulic jack fixed on the hanging beam.

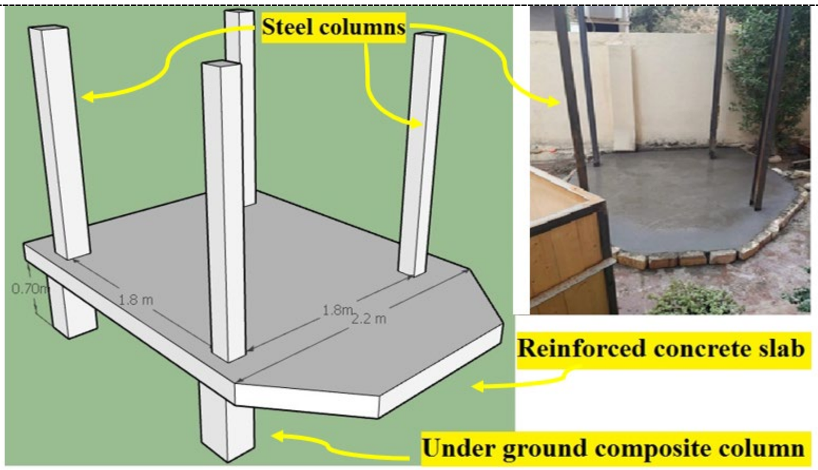

Fig. 3: Casting a base for the container.

Fig. 4: Casting a base for the container.

Fig. 5: Hydraulic jack hanging.

To avoid the torsional stress which maybe occurs during the test, a rigid steel section was welded in a certain way that avoids the torsion and gives a totally fixed support for the jack system. As shown in Fig.6. To measure the slab deflection, a three-dial gages (with their stands) of the same type and properties have been used. It's of a maximum capacity equals 10mm and their accuracy is 0.01mm, as illustrated in Fig.7. The dial gages were fixed by two steel beams (as in Fig.8) at three positions on the specimens, at the center of slab, and at two opposite corners.

Fig. 6: Jack totally fixing.

Fig. 7: Dial-gages details.

Fig. 8: Dial-gages beams.

2.3. Soil properties

The results of laboratory soil tests were shown in table.1 and Table 2. While the sieve analysis data shown in Fig.9.

Table 1. Soil physical properties

Property	Result
Soil classification	SW *
Optimum density from Standard Procter test	18.44 kN/m^3
Optimum water content from Standard Procter test	12.1 %
Degree of compaction	95%
Specific gravity	2.62
Optimum density from modified Procter test	20.55KN/m^3
Optimum water content from modified Procter test	9.1%
Soil elastic modulus	73 MPa
Poisson's ratio	0.3

*Unified soil classification system. Well graded sands, gravelly sands, little or no fines.

Table 2. Chemical properties of soil

Properties	Percentage (%)
Gypsum contain	4.8
SO_3	0.92
ORG	0.48
TDS	0.52
CL	0.042
pH	7.8

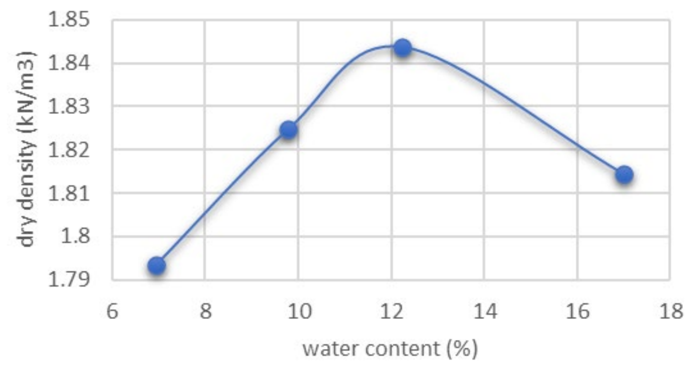

Fig. 9: Standard Procter test results curve.

2.4. Preparing soil for testing

A standard Procter test is performed to estimate the optimum water content and maximum dry density of the soil continuum. The soil weight has to be placed and compacted into the container was detected from that test, as in equation (1):

Soil weight= Dr * bulk density * volume of container (1)

According to S.O.R.B./R5 [12], the Dr factor is compaction field percentage which is ranged between (85 to 95%). It has been taken (95%) in this research. The following steps showed the procedure of soil works:

1. After drying the soil stock from external moisture effect, a balance machine of (100kg) total capacity was used to weight the soil and water that is required for each soil layer. As shown in Fig.10.
2. Reliant on standard Procter test results, the soil was compacted (by a small compacting machine, with vibration, working by gas) in eight layers. Each layer of 150mm. So, the total height of soil is 1200 mm. Manual compacting was also required for compact the soil at the edges of the wooden container where the mechanical compacting machine cannot reach. The compaction process is shown in Fig.11.

Fig. 10: Determining soil weight needed for the container.

Fig. 11: Soil compaction works.

2.5. Concrete mix

The mixing proportions was (1:1.5:3) and the water to cement ratio used was 0.5. In accordance to Iraqi-standards, if the maximum aggregate size is less than 10 mm, then the compressive strength cubes of (100*100*100mm) must be used. So, the compressive strength which were detected from twelve cubes are as shown in Table (3). It is worth to mention that, As ACI-360 committee [3], the major reason to control compressive strength is to ensure that the slab thickness will be enough to convey the load into the subgrade. The same mix was enhanced by adding steel fibers in two different percentages which are 0.5% and 1% to provide more tensile and compressive strength for the plain concrete. As explain in table 3.

Table.3. Cubes compressive strength (MPa)

Compressive strength at 28 days for conventional concrete	30
Compressive strength for steel fiber slab 0.5%	35.4
Compressive strength for steel fiber slab 1 %	39.2

3. Testing results

For all tested specimens, the linear stage of concrete slabs ends at 5 kN approximately which is could be concluded by just watching load versus deflection results. After that stage, the specimens showed the nonlinearity behaviour which means that the model deforms in a manner that could not be back to its case before loading.

From Fig. 12, and from the center dial-gage curve, it could be noting two jumps in the curve at 7 and 9 kN, in which the model cracked at their loads but does not collapse because the soil provides it by bearing capacity, for that reason the deflection increases with a slightly rising in strength. P.S.@C specimen results could be compared with the literature researches for Cajka et al [7]. In which, concrete slab dimensions was slightly less than that of this research slab, which were (500*500*48mm). In addition, Cajka's soil was too much weak than the soil used in this research. The smaller and thicker slab raise the overall ultimate load so the failure load was 18.6kN, and the weaker soil leads to increase the slab settlement so it dropped to 4mm.

After testing the conventional concrete slab specimen, it could be noting that, the concrete slab starts to be bend at the center firstly then the corners suffer from upward. The failure load of the specimen is 17 kN with a total deflection equals approximately 2mm at the slab center as illustrated in Fig. 12.

The essential reason behind increasing strength of steel fiber members is that, the fibers working on gathering the crack and works as small bridges which the stresses passing through so that at Fig.13, it could be clearly see that, the bearing capacity of concrete slab enhanced and developed as well as the deflection decreases when comparing with the conventional member. The same behaviour is also repeated at the 1% steel fiber specimen (Fig. 13, Fig. 14 and Fig. 15). The Concrete slab bearing capacity developed by 44.7% when adding 0.5% of steel fiber and enhanced by 67.03% of it conventional strength when adding 1% of fibers.

Fig. 16 illustrated the crack pattern of the tested specimens. It was concluded that, the reference model shows a brittle failure and few bending capacities because of it was plain concrete without steel reinforcement. While the brittleness was slightly reduced after adding steel fibers because this addition enhanced the ductility of the member. The major cracks were reduced and the crack width also decreased after adding steel fibers.

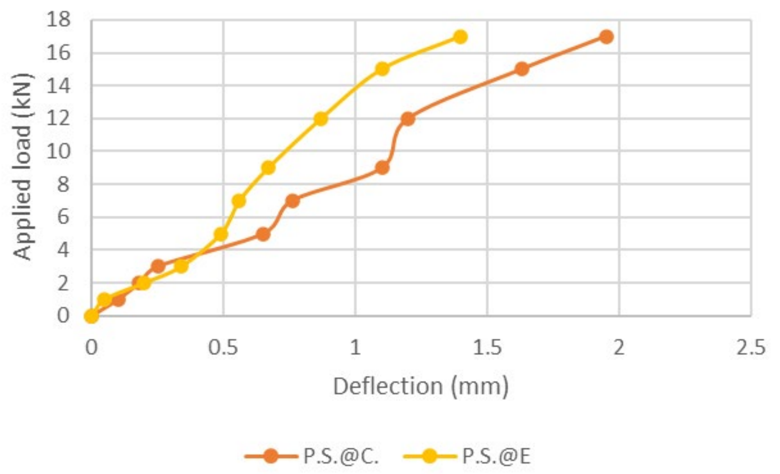

Fig. 12: Load versus deflection curves for conventional slab at center and corner.

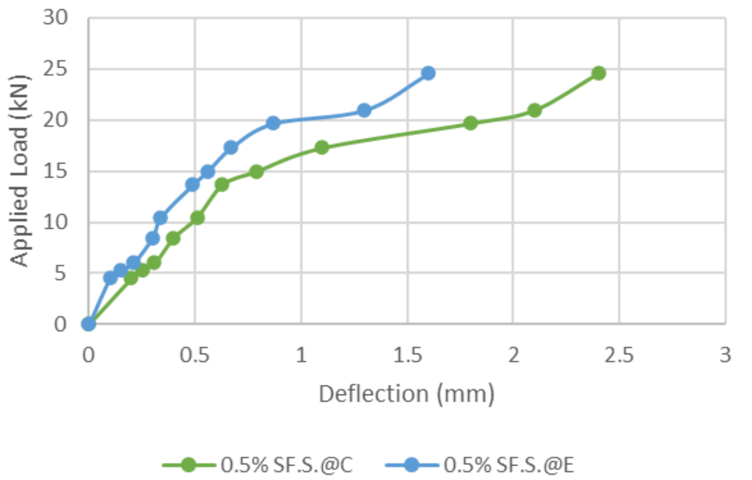

Fig. 13: Load versus deflection curves for 0.5% steel fiber slab at center and corner.

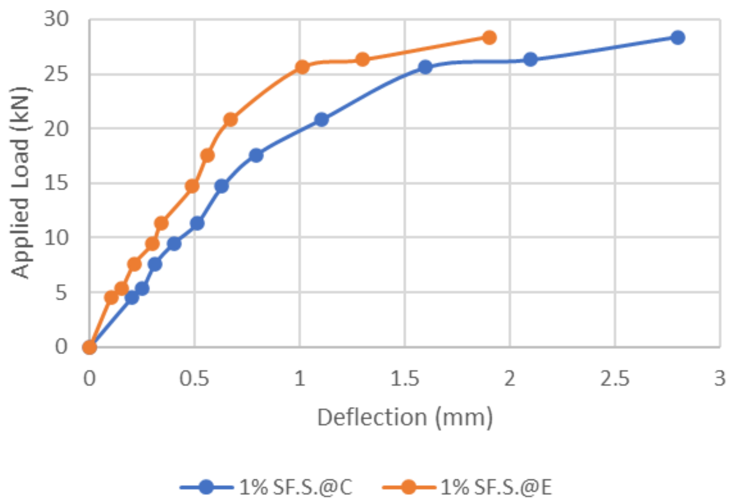

Fig. 14: Load versus deflection curves for 1% steel fiber slab at center and corner.

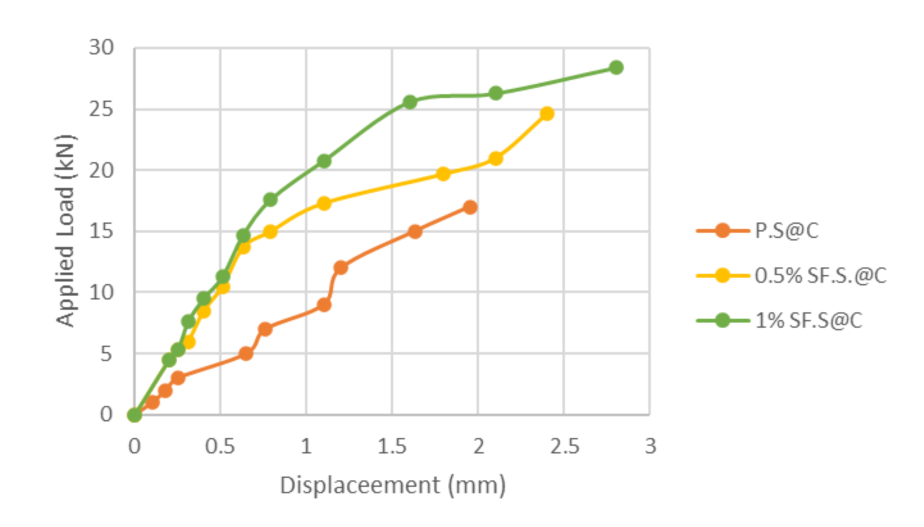

Fig. 15: Comparison between the three specimens.

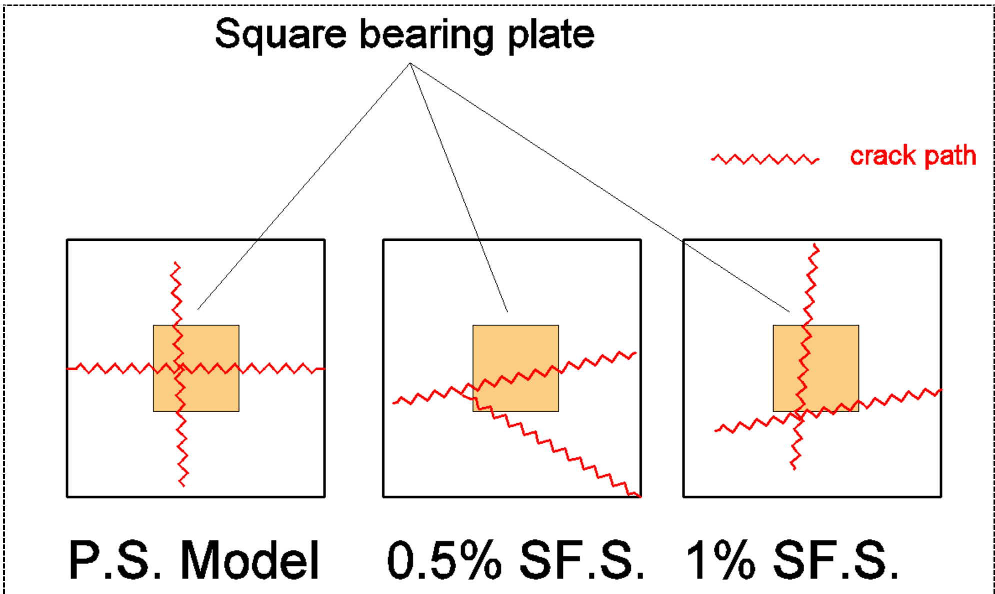

Fig. 16: Mode of failure for tested models.

4. Mathematical model

Mathematical model was investigated for explaining the behavior of concrete slabs and finding the best fitting curve for the results. Many Trendlines were tried to found the best fitting curve for the behaviour of concrete slabs. It was found that, a polynomical equation from the third degree is the best fit for the curve with an efficiency equals 99% and as explain in Table 4.

Table 4. Experimental results mathematical expression

Specimen name	Equation	Efficiency factor R^2
P.S@C	$y = 1.4488x^3 - 11.192x^2 + 30.348x - 0.8078$	$R^2 = 0.9965$
0.5% SF.S.	$y = 3.7446x^3 - 17.588x^2 + 31.126x - 0.9517$	$R^2 = 0.9926$
1% SF.S.	$y = -1.1851x^3 + 3.4091x^2 + 6.4192x + 0.4397$	$R^2 = 0.9889$

5. Conclusion

The study discussed strengthening concrete slabs which rest on soil grade by using Steel fibers. Which is an essential topic for avoiding failling the member due to unexpected load or in case of the designer need to more strength and could not incrase it by increasing slab thickness. Two persentages of steel fiber were used which are 0.5% and 1% of the total volume mix. From the testing results, it could be concluded the following:

1. The square concrete slab bend firstly and settled at the point of load action, then the corners start to be deflected.
2. The the center of slab deflects downward, while the corners go upward then settles.
3. Adding Steel fiber by 0.5% and 1% enhance the concrete compressive strength by 18% and 30.6% respectively.
4. The development in slab strength was 44.7% for 0.5% of steel fiber addition and 67.03% after adding 1% of fibers.
5. The rigidity of concrete slab increase when increasing the fibers.
6. Steel fiber working on matching crack sides so it could be resisting more loads.

From the research, it could be recommonded that, using steel fibers for slabs rest on soil grade is safer to use for important possitions which exposed to extra unexpected loads and it is essential for soils contain gypsum because it leaves voids after dissolving and deteriorate conventional slab capacity.

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