Journal of Engineering and Computer Sciences
Qassim University, Vol. 6, No. 2, pp. 75-91 (Jully 2013/Sha'ban 1434H)

Camber of Skew Precast Prestressed Concrete Bridge Deck Panels

Ahmed F. Elragi[1,2] , and Hany A. A. Dahish[1,2]

[1]*Faculty of Engineering, Fayoum University, Fayoum, Egypt*

[2]*Faculty of Engineering, Qassim University, AlQassim, KSA*

afelragi@qec.edu.sa-dahish4000@hotmail.com

(Received 17/4/2013; accepted for publication 20/12/2013)

ABSTRACT. A common problem that most contractors are faced with in slab-bridges' construction is to predict camber of pre-tensioned or post-tensioned corrugated skew slabs due to prestressing force. It is an important factor to achieve bridge design finished levels without any unforeseen construction cost. Presence of skewedness in bridges makes analysis and design of bridge decks intricate. In this paper, three 3100 mm long post-tensioned corrugated slabs with overall height of 200 mm and 50 mm thickness for both inclined and top parts of specimens, and thickness of 77 mm in the bottom part were studied. Corrugation angle of tested slabs was 60° and skew angle was 20°. Specimens are prestressed by two 15.25 mm diameter strands. Camber measurements were carried out during tests by means of measuring the differences of slab bottom levels. Numerical calculation is done utilizing the Finite Element Analysis Program; ANSYS, taking into consideration initial prestress losses. ANSYS program provides a three-dimensional element (Solid 65) with nonlinear model of brittle materials similar to concrete material. Three-dimensional spar element was used for modeling reinforcement and prestressed strands. Comparison between experimental and numerical results is made. Numerical results showed good agreement with experimental results.

Keywords: Slab, Concrete, Prestress, Skew, Camber, Post-tensioned, Experimental, Numerical, Non-linear.

1. Introduction

In reinforced concrete members the prestress is commonly introduced by tensioning the steel reinforcement. The precast prestressed concrete deck has many advantages, such as eliminating cracks, saving materials, reducing deflection, reducing slab thickness and has been widely and increasingly used in long span structures. In order to analyze these concrete structures accurately and efficiently, several experimental and theoretical models for prestressed concrete structures have been proposed during the past decades [1, 2, 3, 4 and 5]. The use of corrugated precast concrete panel was introduced in 2002 [6]. Researchers approved the actual pronouncement of using concrete in corrugated shape rather than to be used in flat shape.

In this paper, the last studied corrugated panel was adopted, modified, prestressed and made with a skew angle of 20 degree as a simulation of construction type requirement. Accurate camber prediction has the potential to reduce changes and delays in construction. This is achieved by eliminating adjustments in build-up or bearings that are otherwise required to arrive at the correct deck profile. The paper is primarily focused on obtaining camber data in order to compare with the numerical results. The evaluation is done with the goal of verifying the current FE model to be used as a design tool for camber estimation.

Experimental investigation is carried out on skew precast reinforced folded corrugated panel to determine its camber under prestressing process loading using different shape of top surfaces. The theoretical study is made using the finite element method to model the reinforced concrete precast panel.

Mohamed [6] investigated the effect of corrugation angle on precast prestressed panel, but the study does not take skew angle into account in the experimental or theoretical studies. Tyler [9] presented the results of field research to investigate factors related to prestressed concrete girder production that could affect the camber and to recommend camber prediction methods. These factors include; higher concrete compressive strength than specified, curing method, girder type, changes in cross section due to deformation of internal void forms, strand de-bonding, and transfer length. A refined camber prediction method [9] was developed that uses creep coefficients and prestress losses based on the 2010 AASHTO LRFD Bridge Design Specifications [10]. An approximate method based on the PCI camber multipliers was also proposed [9]. Both methods compared well with the measured cambers of 382 prestressed concrete bridge girders, though the former was more accurate for the majority of girders.[9] . PCI Committee on Bridges [11] presented guidelines for the design, manufacture and erection of precast prestressed concrete bridge deck panels. This research was conducted to develop improved methods of predicting camber in prestressed concrete girders [9]. A computer program [8] was written to calculate camber as a function of time. It takes into account instantaneous and time-dependent behavior of the concrete and steel and performs the calculations in a series of time steps. It was calibrated by comparing its predictions with the camber from girders, measured in the fabricators yard both after release and at a later time.

In the check of Dahish et al. [12] study, using experimental investigation to study the behavior of composite slab with reinforced and prestressed concrete precast skew panels and prestressing under cyclic loading. They concluded that the mode of failure for all specimens was flexure. In addition the increase in percentage of shear keys increases capacity of specimens and decreases tensile and compressive strains. The cyclic loading decreases stiffness of specimen with increase of number of cycles at the same load. They also concluded that the skew and geometry of the composite deck affects crack pattern on the bottom surface of specimens.

2. Experimental Program

To determine the camber due to the effect of prestressing force on skew corrugated concrete precast panels, three specimens of 3100 mm long post-tensioned corrugated slab were prepared. The overall height and thickness of specimens are 200 and 50 mm respectively for both inclined and top parts of the specimens, and thickness of 77 mm for the bottom part as shown in Figure (1). The corrugation angle of the tested slabs was 60° and skew angle of 20° as shown if Figure (2). The specimens were prestressed by two 15.25 mm diameter strands for each one.

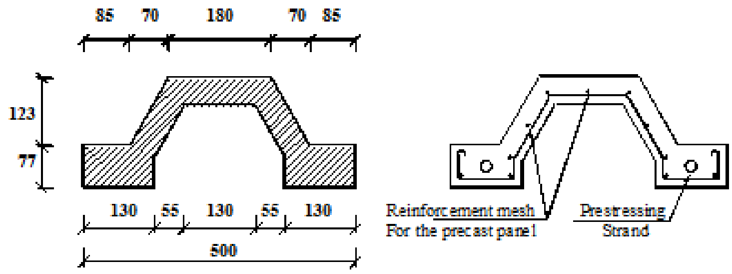


Fig. (1). Dimension of slab and reinforcement (all dimensions are in mm)

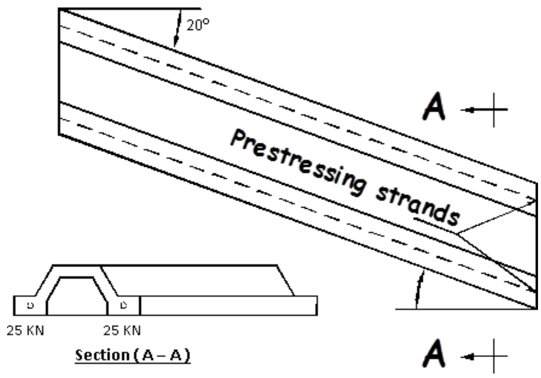


Fig. (2). Prestressing forces for all specimens

2.1 Materials

The materials used in preparing the tested specimens were locally produced. Two types of aggregates were used in preparing the concrete specimens, fine aggregate (sand) and coarse aggregate (crushed stone). The fine aggregate used in preparing test specimens was siliceous sand free from deleterious materials. The crushed stone used had a nominal maximum size of 12.5 mm. This nominal size was chosen taking into consideration the dimensions of cross section of the precast slab as well as the spacing between the reinforcement bars. The aggregate composition used in the concrete mix was 66 % crushed stone and 34 % sand.

Tests were carried out to determine mechanical properties of the materials according to Egyptian Standard Specifications. The type of cement was “Egyptian Ordinary Portland Cement" with amount of 500 kg/m^3. Clean fresh water was used with a water cement ratio (w/c) of 0.38 by weight of cement. A water reducer admixture was used in concrete mix for workability increase with a percentage of 1.5 % by weight of cement.

The steel reinforcements used were mild steel bars of 6 mm in diameter in the longitudinal and transverse directions. Properties of reinforcement bars were determined using tests according to the Egyptian Standard Specifications. Tests results are reported in table (1).

Table (1). Mechanical properties of 6 mm reinforced mild steel bars

Yield stress	355	MPa
Ultimate strength	495	MPa
Elongation	24	%
Young’s modulus	195000	MPa

All panels were prestressed by two 15.25 mm diameter 7-wire strands produced by Dywidag, Germany. The tensile properties of the prestressing steel strands were evaluated based on the manufacturer data of 15.25 mm and a tensile strength of 1860 MPa.

2.2 Design of concrete mix

The absolute volume method was used to determine the concrete mix proportions. Table (2) shows the proportions of the concrete mix. Table (3) shows the properties of the materials

Table (2). Concrete mix for precast panel

Layer	Mix proportions by weight					Cement	Water	Admixture
	Cement	:	Sand	:	Crushed stone	kg/m^3	(liter)	(liter)
Precast	1	:	1.2	:	2.4	500	190	6.00

Table (3). Properties of materials

Group	% Top Surface	F_{28} MPa	F_{test} MPa	F_t MPa	$F_{split.}$ MPa	E MPa
Prestressed Panel	0	37.6	46.7	8.8	3.3	36700
	20	34.1	42.7	7.6	3.0	35100
	40	36.4	45.5	7.9	3.2	36300

2.3 Preparation of specimens

For the precast layer, the required form were prepared one hour before mixing the concrete, all trapezoidal boxes and sides of the form were coated by thin layer of form oil to facilitate the removal of the forms after concrete hardening. The reinforcement was placed and tied to the form. A great care was taken during casting to keep the steel strain gauges in save position.

A mechanical mixer of vertical axis was used to mix the concrete. The time of mixing about three minutes, half a minute to mix the dry materials till a uniform color is observed and then mixing with water for about two and half minutes.

Fig. (3). Electrical Strain Gauges on Steel

Fig. (4). Steel mesh, Anchors and Rubber inside the Form Wood

The concrete was mechanically compacted during casting of the precast layer using rod type vibrator together with hand taping and prodding to insure full compaction of the concrete inside the form.

After 6 hours of casting, the three movable trapezoidal boxes were removed while, the longitudinal and the back sides of the form were kept in their position for another 18 hours. The top surface of the precast slabs were covered by wet burlap for 48 hours, then cured twice daily with fresh water for a total period of 8 days (Figures 5, 6, and 7).

Fig. (5). The Specimen after Form Removal

Fig. (6). Specimen and the Strands

Fig. (7). Measurement of specimen Dimensions

2.4 Test setup and instrumentation

The assembly of slab was carried out by putting the specimen on temporary supports. After that the two prestressed tendons were laid through the anchorages. The prestress load was applied using a jack of 200 KN in capacity at each tendon. The vertical deformations were measured using mechanical dial gauges as shown in Figure (9). Camber measurements were carried out during the test by means of measuring the differences of slab bottom levels. Prestressing steel strands were prestressed to reach 25 KN for each strand. The jacking forces were measured for each panel using load cells. Figures (8) and (10) show the jacking operation of the prestressed strands.

Fig. (8). Prestressing process of the strand

Fig. (9). Camber measurement using dial gauge

Fig. (10). Strands after prestressing process and the anchor wedges

3. Analytical Model

All of the specimens were simulated with ANSYS [13] as shown in Figure (13), which offers a series of very robust nonlinear capabilities for design and analysis. A routine was written in ANSYS to model prestressed corrugated precast concrete skew panels. The concrete element adopted in the present FE model is SOLID65, 3-D reinforced concrete solid element. SOLID65 (Figure 11) is used for the three dimensional modeling of solids with reinforcing bars (rebars). The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element is capable of cracking in tension, crushing in compression, having creep nonlinearity and large deflection geometrical nonlinearity. The peak strength *f*c, initial young's modulus *E*c, and other parameters in the model were assigned according to test data. Two shear transfer coefficients, one for open cracks and other for closed ones, are used to consider the re-tension of shear stiffness in cracked concrete.

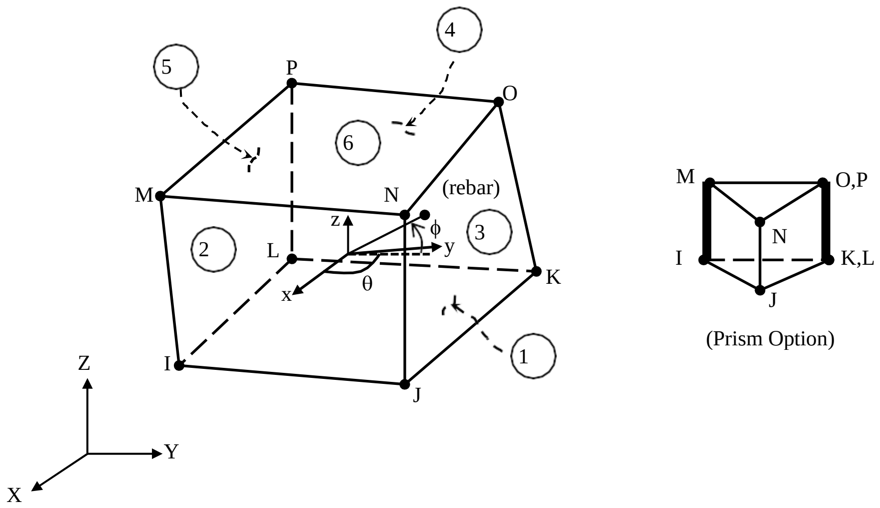


Fig. (11). The geometry, node locations and the coordinate system of SOLID65 element

The used element for modeling of reinforcement and strands was Link8 (Figure 12). The three dimensional spar element is a uniaxial tension-compression element with three degrees of freedom at each node. The bar was modeled as an elastic perfectly plastic material, and the strength was defined according to the data in the test.

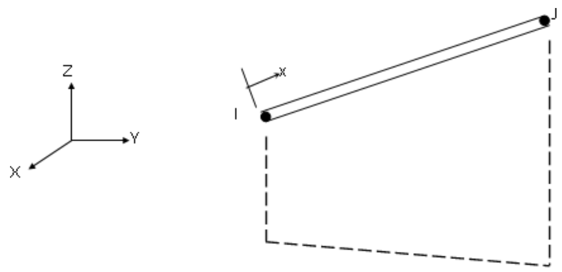


Fig. (12). The geometry, node locations and the coordinate system of Link8 element

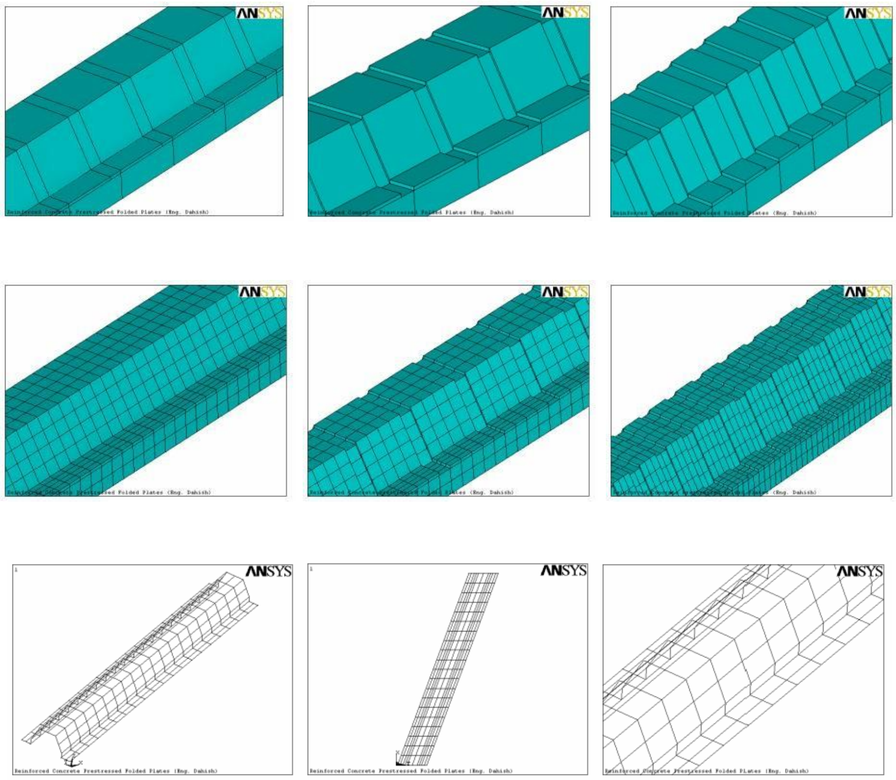
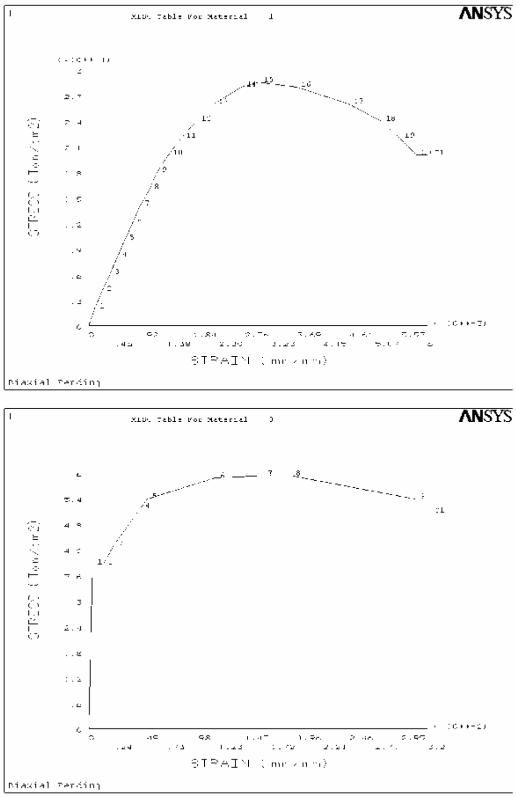


Fig. (13). F.E. Meshed Element models for concrete and steel bars

A multi-linear stress strain curve for concrete is used. A typical behavior expressed in the stress-strain relationship for concrete and steel is shown in Figure (14) for all models in the present study based on tests results.



Concrete Steel

Fig. (14). Typical concrete and steel behavior under uniaxial loading

Panels are pinned at the lower surface at the two supports as shown in figure (15). Specimens were loaded by means of initial strain in the strands.

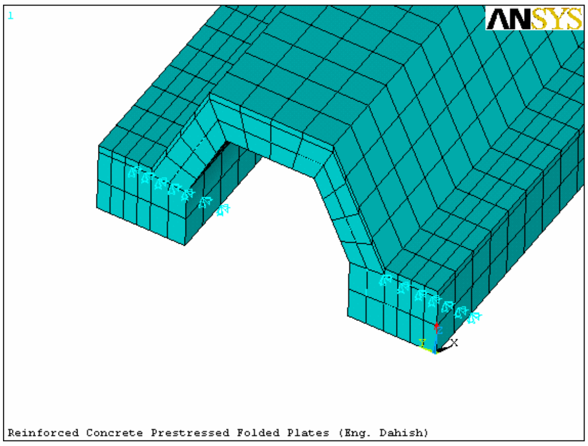


Fig. (15). Restraints for specimens

Because of the non-linear nature of plasticity, non-linear solution control with automatic time stepping is used to control convergence. The full Newton-Raphson method with adaptive descent is used to solve the non- linear equations. Non-linear solution control functions are implicit in ANSYS, and default parameters are used.

Analysis assumptions made for specimen models in this study to provide reasonably good simulations for the complex behavior are as follow:

- Bonds between each element/material type are assumed perfect. Unless the failure mode of a structure involves a bond failure, the perfect bond assumption used in the structural modeling will not cause a significant error in predicted deflection response.
- Poisson's ratio is assumed to be constant through the loading history.

Camber prediction for tested specimens were calculated, deformed shapes are obtained for each slab.

4. Results and Discussion

Vertical movements at mid span for different surface shapes of specimens are measured experimentally. Results show that the form of the top surface of the specimens affects the camber as shown in Figure (16).

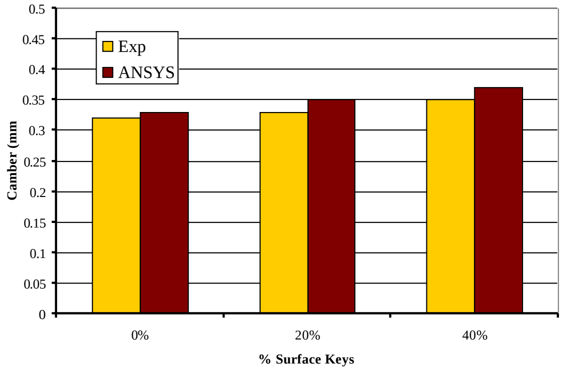


Fig. (16). Comparison between Experimental and Numerical Results

On examining the numerical results for all specimens, it was found that the numerical results show good agreement with the experimental measurements. Figure (16) shows a comparison between numerical and experimental results. The differences between numerical and experimental measurements were less than the ratio of 6%. It can be seen that the proposed model gives a favorable results in comparison with experimental results. In both experimental and numerical results deflection increase as the surface keys increases.

The effect of the skewedness on the specimens is shown in Figure (17). It can be seen that as the skewedness increases the deflection increases for all three monitored points (middle, third and quarter) this may be due to torsion effect. For skew angles less than 30 degrees it can be seen that the rate of increase of deflection is less than that of skew angles more than 60 degrees.

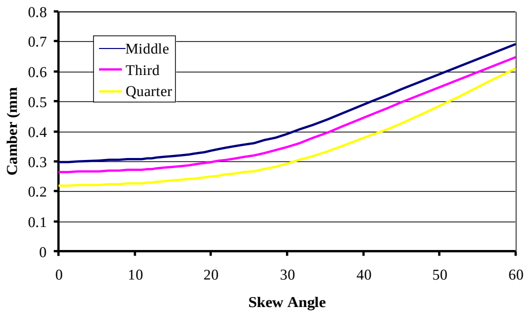


Fig. (17). Variation of Camber with Skew Angle at Different Locations with Web Angle = 60°

Typical pattern of deformed shape is shown in Figure (18). The maximum deformed shape is in the middle and decreases as we move away both sides. Figure (19) shows the deformation variation over the span for different skewedness and different web angles. It can be seen that deformation increase with the increase of the web angle as well as the increase of the skewedness.

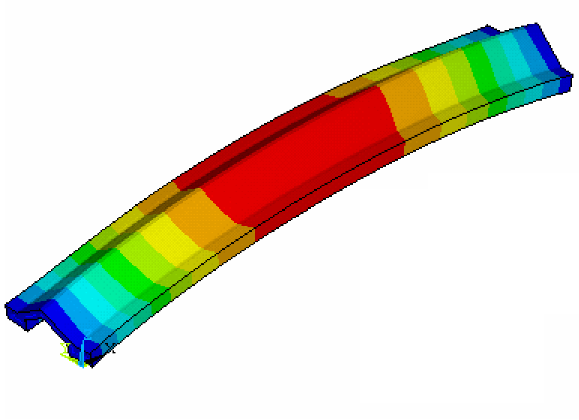


Fig. (18). Typical Deformed Shape

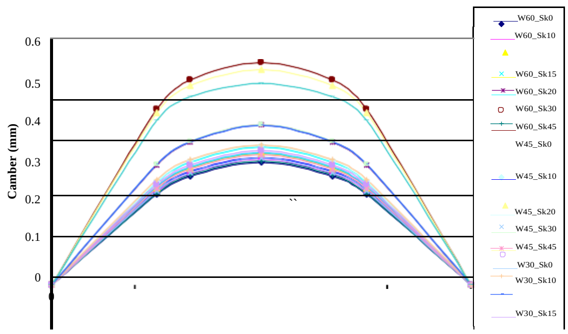


Fig. (19). Variation of deformation with span for different skew and web angles

5. Conclusions

In this study, experimental and numerical investigations were made to study camber prediction for precast prestressed reinforced concrete skew panels.

A number of tests were conducted to study the prediction of camber for post-tensioned prestressed concrete skew panels due to prestressing effect. Numerical analysis was conducted to model the behavior post-tensioned prestressed concrete skew panels due to prestressing effect. The behavior of the slabs was evaluated in terms of vertical deformation, the following conclusions were obtained:

1. The shape of the specimens affects camber prediction.
2. Camber is affected by percentage of surface keys, skewedness as well as web angle.
3. As the percentage of surface keys increased camber increases.
4. As the skew angle increase camber increases with slight rate at values less than 30 degrees and higher rates above 30 degrees.
5. As the web angle increases camber increases.
6. FEM is an effective method for analyzing the camber prediction for precast prestressed reinforced concrete skew panels.

6. References

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التحدب في وحدات الكباري المنحرفة عن المحور المصنعة من خرسانة سابقة التجهيز سابقة الاجهاد

أحمد فؤاد الراجى(١،٢)، **وهاني داهش**(١،٢)

(1) كلية الهندسة – جامعة الفيوم – الفيوم – مجهورية مصر العربية

(2) كلية الهندسة – جامعة القصيم – القصيم – اململكة العربية السعودية

dahish4000@hotmail.com - afelragi@qec.edu.sa

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ملخص البحث. هناك مشكلة مشتركة تواجه معظم املقاولني يف البناء مع لوو اسسوور ه هوو الؤنبود ابودود من ألوا االحنراف امرو امؤوم م قبول أو بعود امؤوم م بسوب قوود املجهواد امسبم هوو تامول مهوم لؤ قيوم الؤصميم االنؤهاء مسؤويات اسسر دون أي تكلفة البناء غري مؤوقعة وجود أي احنراف يف اسسور جيعل حتليول ونصميم جسور الووابوم معقودد يف هولو الورقوة واة دراسوة و ووة ألوا وجوة 2111 ملوم وويلوة بعود املؤم م مع االرتفاع الكلي 211 ملم و 01 ملم مسو لكو أجو اء موي وأتلو مون العينات ومسو 11 ملم يف اس ء السفلى كان اويج اوية من ألوا اخؤبار 01ْ و كوان اويوة االحنراف 21ْ و مسوبقة املجهواد العينات من قبل اونى من 10.20 ملم خيوط القور أجريوة القياسوات ابودود مون خو ج الؤوار الو قامة بها وسائل لقيوا االخؤ اوات يف مسؤويات القواع بووة ويوؤم السوا العوددي باسوؤمدام برنامج حتليول العنا ور اةودود؛ ANSYS موع اذخول بعوى االتؤبوار سووائر prestress اذولوي يووار برنوامج ANSYS تنصر ووي اذبعاد) الصولبة 00 (موع ووو غوري ا ووية مون مواد هشوة اولوة ملواد ملموسوة اسؤمدام تنصر الصاري ووي اذبعاد للملجة و تعي مسارات املجهاد يؤم املقارنوة بوني النؤوائج الؤ ريبيوة والعددية وأظهرت النؤائج العددية اتفاق جيد مع النؤائج الؤ ريبية