A Strengthening model for concrete frames using diagonal tendons

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ABSTRACT: In this work, a computational model suitable for analytical solution of frames with diagonal tendons is presented and checked experimentally. The comparison between computational and experimental model is carried out using dynamic loading. The transient dynamic analysis of the ANSYS program is used for the finite elements analysis. In the experimental process a plane strain model made of PMMA is used. This specimen represents a half space uniform soil in which a frame with diagonal tendons is founded. The stress pulse propagation in the specimen is studied by means of the optical method of caustics.

1. INTRODUCTION

The stiffness strengthening of existing buildings that can't satisfy recent requirements as EC8, Giaka (1996), is in general big problem, especially in countries with strong seismic wave action, like Greece. One of the stiffness strengthening method, which is appropriate for existing structures with a structural system consisting of frames, is the using of diagonal tendons. The diagonal tendons can be applied to existing reinforced concrete frames to improve their stiffness in order to resist horizontal earthquake forces. Some of the benefits of this solution are as follows :

- It can be easily applied.
- No large scale damages of the existing structure are necessary.
- It is an economical solution compared with the others.
- It can be set into the brickwork allowing large openings.

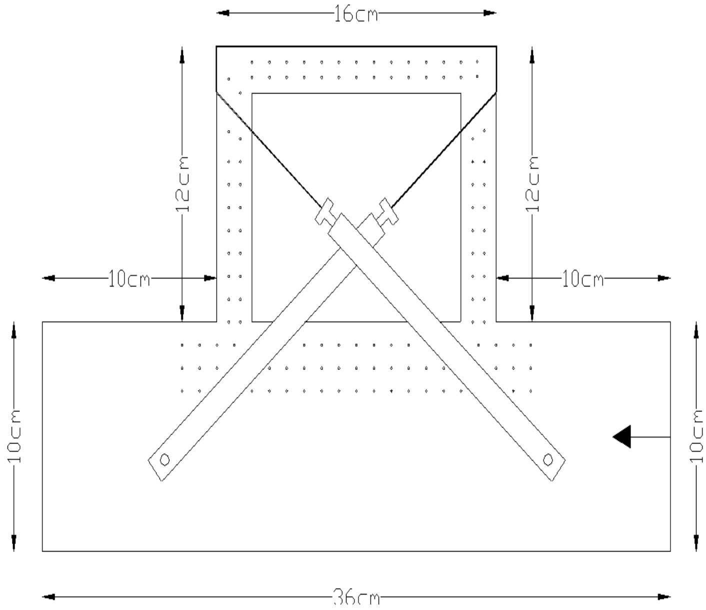
The difficulty consists to solve this problem accurately, because non linear analysis is necessary. Many computational models can be proposed but a scepticism about their accuracy and faithfully will be always exist. The proposal finite element model which was developed using ANSYS program, has been checked experimentally at the Lab. for Testing and Material of NTUA. A suitable to the experimental process model has been used and compared with a corresponding model which has been developed according to the proposal finite element analysis. Comparison of experimental and dynamic analysis results for stress pulse propagation have already been presented, Badalouka (1995, 1996).

2. EXPERIMENTAL ARRANGEMENT

The specimen was made of PMMA of thickness 3 mm. The shape and dimension of it are shown in Figure 1. It consists of the 'base' and a two column single frame. The tendon was a wire of steel of diameter 0.4 mm, which had been placed diagonal through two holes also perforated diagonal at the top of each column under the top of the frame. These oblique holes had a diameter of 1.2 mm. The ends of the wire came through two bolts, which had been placed at the top of two small frames of Lexan connected with the 'base' of the specimen by a pin. The wire was gradually tensioned rotating the two bolts . The specimen were impact in horizontal direction by a projectile which was fired out of an air gun , with velocity of about 10 m/sec. The projectile were a steel sphere of diameter 10 mm. The detection of the stress pulse propagation became by the optical method of caustics, Theocaris (1970), Papadopoulos (1993). The caustics formed around small holes perforated in square arrays constitute stress-rosettes, Theocaris (1976). The shape of caustics, (Fig.2), and its dimensions, depend on the stress distribution and the orientation of the principal stresses at the boundary of the hole. This yield directly the principal stress directions of the stress field, as well as the principal stress difference from the follow equation:

$$Dmax = 8/3 \; (12\, C\, \lambda^3 R^2 \,|\, \sigma_1 - \sigma_2 \,|\,)^{1/4} \qquad (1)$$

where Dmax is the maximum diameter of caustic, C is the stress optical constant, λ is the magnification ratio of the optical set-up, R is the radius of the hole. The recording of the dynamic effect was obtained by a Cranz-Schardin high speed camera disposing 24 sparks with a max frequency of 10^6 frames per sec.



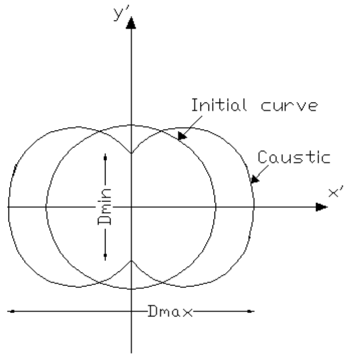


Figure 1. The specimen Figure 2. The caustic

3. BUILD THE MODEL

The transient dynamic analysis, (TDA), of the ANSYS program was used. TDA is a technique used to determine the dynamic response of a structure under the action of any time-dependent loads The basic equation of motion solved by a DTA is :

$$[M]\left\{\ddot{u}\right\}+[C]\left\{\dot{u}\right\}+[K]\{u\}=\left\{F_{(t)}\right\} \qquad (2)$$

where [M], [C], [K] are the mass, damping and stiffness matrix respectively, $\{u\}$, $\{u\}$, $\{u\}$ are the nodal acceleration, velocity and displacement vector respectively and $\{F_{(t)}\}$ is the load vector. ANSYS programme uses the Newmark time integration method to solve these equation at discrete time points.

Four-nodal elements, plane 42, (42 means 4 nodes with 2 DOF per node), of thickness 3 mm were used to describe the specimen. For modelling the wire, the element LINK 10 tension - only and prestress with $\Delta l/l=0.005$ was used. Element LINK 10 is a spar with 1 DOF. For the description the area of the oblique holes, (at the top of the columns), the elements plane 42 were also used, of thickness 1.8 mm (the difference between the thickness of the specimen and the diameter of the oblique hole). For modelling the wire - specimen contact condition, the elements LINK 10 compression only, (spar with 1 DOF), were used, with modulus of elasticity equal to the steel one and section the wire-oblique hole area. In addition, plane 42 was also used at the wire-oblique hole contact condition, with modulus of elasticity as follows : Ex a very little value, Ey equal to PMMA modulus of elasticity.

To specify load as function of time, the load versus time curve had been divided into three steps as follows:

First step: Time 0-50 μsec, Forces Fx, Fy 0-50 Kp at 10 substeps.
Second step: Time 50-100 μsec, Forces 50-0 Kp at 10 substeps.
Third step : Time 100-200 μsec, Forces 0 Kp at 10 substeps.

4. RESULTS

Figure 3a presents an experimentally frame at time 48 μsec from the beginning of stress pulse propagation. The stress pulse front has just arrived at the lower right column of the frame as we can see from the large caustics that have been created there. The direction of the compressive stress corresponds to the direction of the maximum diameter of the caustic and this is depended of the optical set-up. The smaller caustics that have been created at the frame are initial stresses due to the prestress tendon. Figure 3b presents the principal stresses by TDA at corresponding time of propagation (50 μsec). As we can see there is a very good agreement between the orientation of principal stresses of the two methods especially to the right side. The more intensive stresses that have been obtained by TDA at the left side, due to the direct wire-specimen contact by this method, in contrary experimentally this contact took placed through the little frame of Lexan that gave a delay time of the stress propagation.

Figure 4a also presents an experimentally frame of the right column at time 72 μsec from the beginning of propagation. Figure 4b presents the orientation of compression stresses, that correspond to the maximum diameter of the caustics. Figure 4c presents the principal stresses at the same area and corresponding time of propagation (70 μsec), by TDA. Figure 5a presents experimentally principal stress at time 128 μsec. The orientation and the length of each line also correspond to the maximum diameter of the caustics. Figure 5b presents the corresponding stresses (130 μsec), by

Figure 3a. Orientation of caustics at 48μsec.

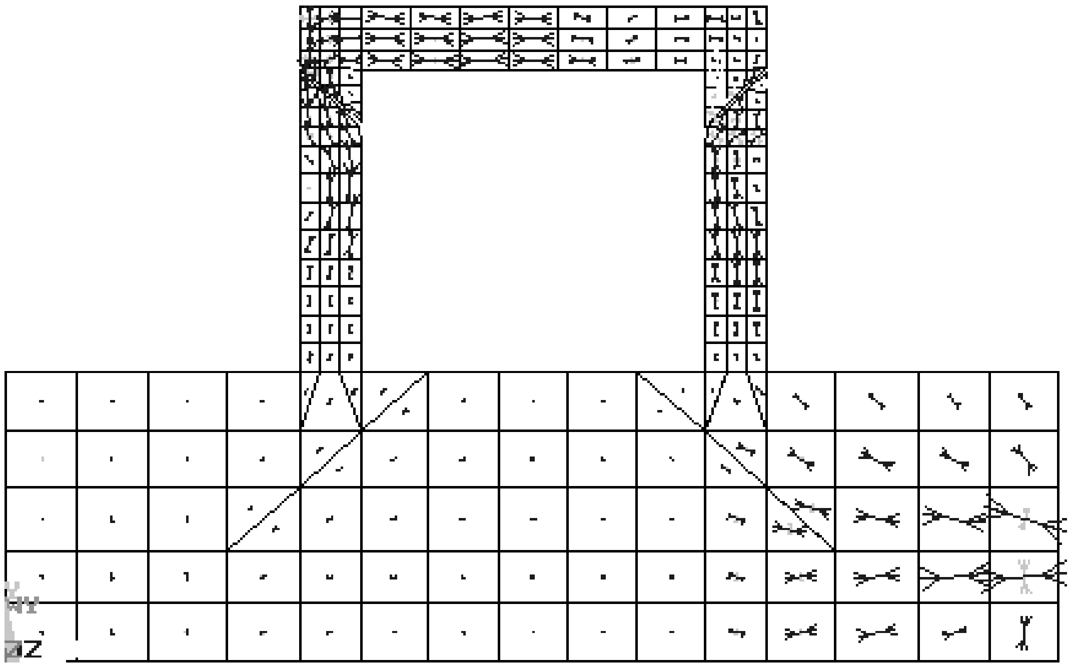


Figure 3b. Principal stresses by TDA at 50μsec.

Figure 4a. Orientation of caustics at 72μsec.

Figure 4b. Orientation of max diameter of caustics at 72μsec.

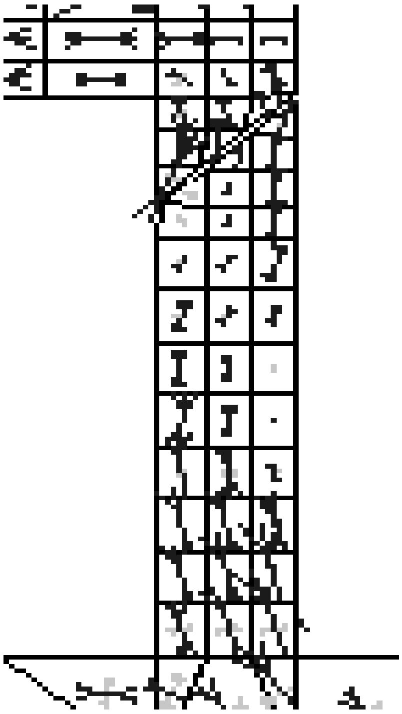


Figure 4c. Principal stresses by TDA at 70μsec.

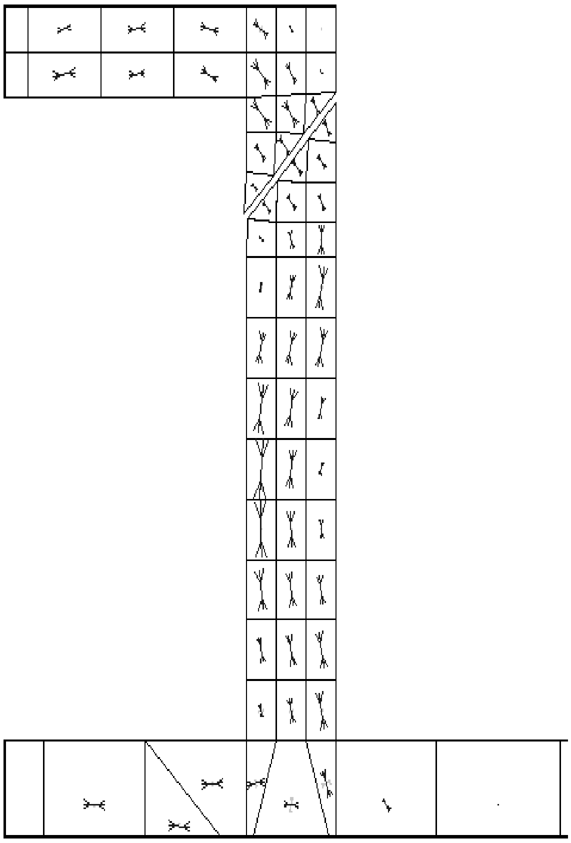


Figure 5a. Orientation of max diameter of caustics at 128μsec.

Figure 5b. Principal stresses by TDA at 130μsec.

TDA. As we can see there is a good agreement between the orientation of principal stresses. We can also observe that the areas without stresses are about the same.

5. CONCLUSIONS

In this work an experimental model simulating frame with diagonal tendon has been used and compared with corresponding model which had been developed according to proposal finite element analysis. As the results of the comparison gave a good agreement, the proposal analytical model can be used to describe and solve faithfully and accurately various problems of stiffness strengthening using diagonal tendons.

6. REFERENCES

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