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FULL SCALE TEST ON STEEL ARCH WITH NON CONVENTIONAL PURLIN UNDER LATERAL AND GRAVITY LOADS

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RESUMEN

En el presente reporte se propone el uso de una vigueta no convencional de sección triangular con diagonales cruzadas para ser usadas en estructuras de arco. Se construyo un arco de 7 metros de luz con viguetas de 6 metros para investigar el comportamiento frente a cargas de gravedad extremas y cargas laterales monotonicas. Para probar la interacción entre el arco soporte y las viguetas se aplicaron cargas incrementales sobre cada elemento encontrándose una deflexion elástica del orden de 0,007 m. para una carga repartida de 931N/m para una demanda de las especificaciones AISC-LRFD (L/360). Se encontró una deflexion máxima al final del ensayo del orden de 0,013 m. para una carga repartida sobre las viguetas de 1470 N/m. Para probar la efectividad de la conexión empernada entre arco y viguetas, un ensayo a escala natural bajo aplicación de carga lateral monotonía fue desarrolladas a manera de simulacion de una carga de viento extremo sobre la estructura. Se encontró que para un desplazamiento lateral del sistema de 0,05 m. la carga producida fue de 2254 N. Este valor de carga se encuentra en el inicio del comportamiento no lineal del sistema estructural.

ABSTRACT

A non conventional purlin with triangular section and cross diagonals is proposed to be used in Steel Arch Structures. For this purpose a full scale arch of 7 meters span with 6 meters purlins, was built in order to perform a loading test under extreme gravity loads and monotonic test under lateral load. To prove the interaction between the supporting arch and the purlins, incremental gravity load was applied over each element. Elastic deflection of 0,007 m for 931 N/m load was found which is under the demand of AISC-LRFD (L/360). Maximum deflection of 0,013 m for 1470 N/m load was found at the end of the test. To prove how effective is the bolt connection between the purlin and the arch, a full scale test under lateral monotonic load applied at one extreme was performed, to simulate the extreme wind load over the structure. A 2254 N load produces 0,05 m of lateral displacement on the system. This value was almost the beginning of the non-linear behavior of the structural system.

INTRODUCTION

Steel Arch Structures are widely used as a large span solution for roof of gymnasiums, coliseum, factories and others. However, in third world countries, the reduction of cost of such system depends of the structural configuration. In order to reduce the weight of the system, the use of non conventional purlin with triangular section and cross diagonals is proposed. For this purpose a full scale arch of 7m span with 6m purlins, was built in order to perform a loading testunder extreme gravity loads and a monotonic test under lateral load. To prove the interaction between the supporting arch and the purlins, incremental gravity load was applied over each element. Elastic deflection of 0,007 m for a for 931 N/m load was found which is under the demand of AISC-LRFD (L/360). Maximum deflection of 0,013 m for

1470 N/m load was found at the end of the test. The results show that non conventional purlins has good behaviorunder extreme gravity loads.

In order to estimate an extreme wind load, a numerical simulation for the test structure was performed showing an expected maximum lateral load of 2254 N on the extreme for 30,58 m/s of wind velocity. Then, to prove how effective the bolt connection between the purlin and the arch is, a full scale test under lateral monotonic load applied at one extreme was performed, to simulate the extreme wind load over the structure. A 2254 N load produces 0,05 m of lateral displacement on the system. This value was almost the beginning of the non-linear behavior of the Structural system. Finally, the system with non-conventional purlins shows good behavior under gravity and lateral loads, which is an alternative to reduce cost on this kind of structure.

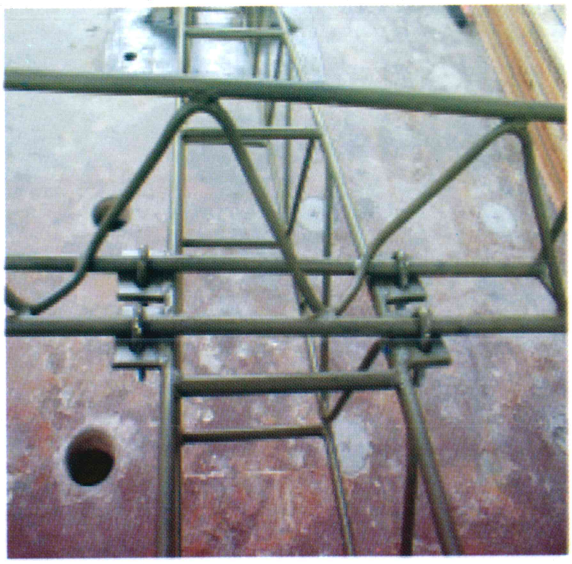

Fig. 1 Arch Section and Proposed Purlin.

Loading test under extreme gravity loads

About the testing.- The most likely used method to verify the gravity load capacity is the Loading test. In this case ASTM E73, Standard Practice for Static Load Testing of Truss Assemblies has been followed in the perform of the test. Three 6 m full scale purlin specimens pin supported over a full scale 6,8 m arch are tested. The arch has a central height of 1,54 m with section made of four 0,0125 m diameter bars with a depth of 0,245 m., fixed with diagonals of 0,38 m span and a width of 0,205 m. The arch is confined by purlins spaced 1,54 m. with light steel decks of 49 Pa of weight.

Fig. 2 Full scale Testing.

A conventional purlin has diagonal bars in three planes of its triangular section, but this non conventional purlin have a pseudo triangular cross section with 0,083 m base and 0,155 m height and use 0,0125 m diameter bars that forms continued and alternated diagonals in the planes of it section, as is shown in Fig. 1. A structure configuration of the system is presented in Fig. 2 and location of measuring devices is presented in Fig. 3.

Test procedure

The test considers the application of incremental gravity loads over the pin supported purlins. In order to apply the load, wood panels over the purlins were placed with a death load of 143 Pa. The panels were distributed over the decks in order to simulate the live load over the purlin. Each increment of load was produced by an increment of wood panels number as is shown in Fig. 4. Each increment of load produce an increment of deformation which is registered by a group of 11 sensors, distributed under the purlins as is shown in Fig.3.

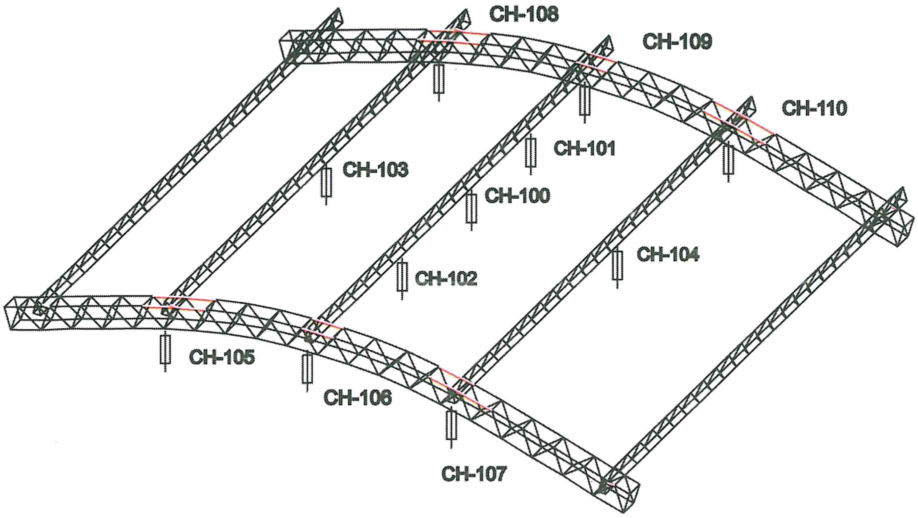

Fig.3 *Test structure and Test Setup for Loading Test.*

Fig. 4 *Gravity load Increment on Testing.*

Maximum estimated load

According with the Peruvian Construction Standards NT-E20, the roof load over this kind of structure should be L=294 Pa. Considering the existing loads (Self weight of the purlin and deck panel) a dead load D=98 Pa is taken to carried out the approximate ultimate load using the LRDF-AISC 99 load combination, then, Pu = 1,4 D+1,6 L = 607,6 Pa. If the purlin are set each 1,54 m, a uniform maximum load Wu=1,54 Pu = 935,9 N/m is consider to satisfy the standards under gravity load.

Results

Following the ASTM E-73 standards, the structure was loaded as described in item 2.2. The incremental load was applied until reach the LRFD requirement. Because at this load level, the structure was completely elastic, the load was incremented until a value up to 1764 N/m on the purlin. Then, under this load and during 24 hours the monitoring system took measures each hour.

Figure 5 presents the results of load - displacements curves for the three purlins, two lateral purlins and a central purlin, all of them pin supported over the arch. The presented displacement is the relative displacement of the purlin. From the results is read that in all the cases, when the LRDF requirement (935,9 N/m) is applied the purlin is on the elastic range. Therefore, the maximum values are over 40% of the maximum requirement of LRFD. An elastic deflection of 0,007 m is produced for the LRFD requirement on the purlin. A maximum displacement of 0,0167 m (L/360) was reach during the loading test. Then, the proposed non-conventional purlin satisfied the requirement of the AISC Standards and is an economical solution for this kind of structure.

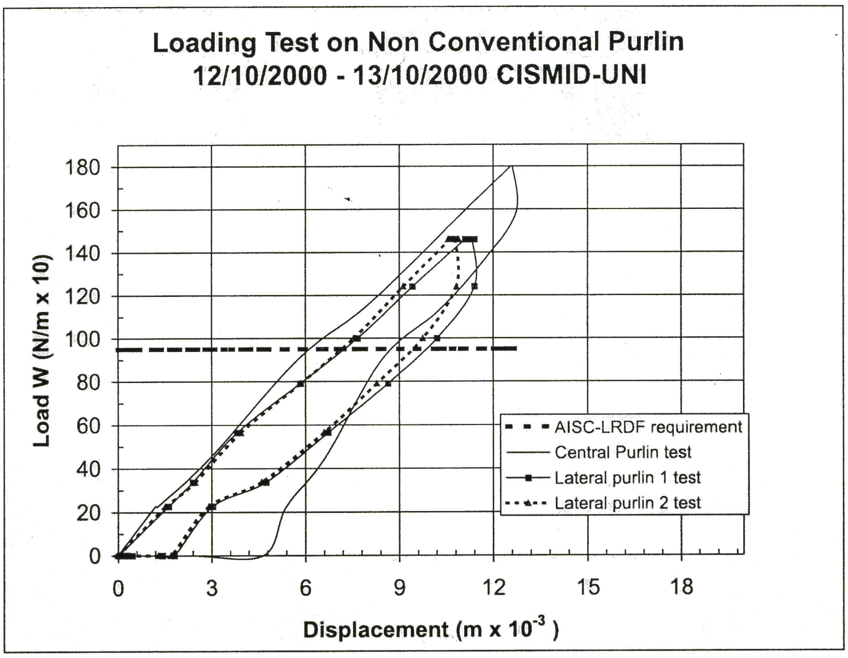

Fig. 5 Test Results for three purlin specimens.

LATERAL LOADING TEST

About the specimen and test setup

After perform the gravity load test, the specimen presented in item 2, was used to perform a lateral load test, in order to simulated wind or earthquake load effects. The test objective is verify the structure lateral capacity using the proposed purlin with bolted joint connected to the arch and research the load level on a non-braced arch-purlin system. For this purpose the lateral load is applied at each purlin edge, and seven sensors are set to record the displacements during the load application as shown in Fig. 6.

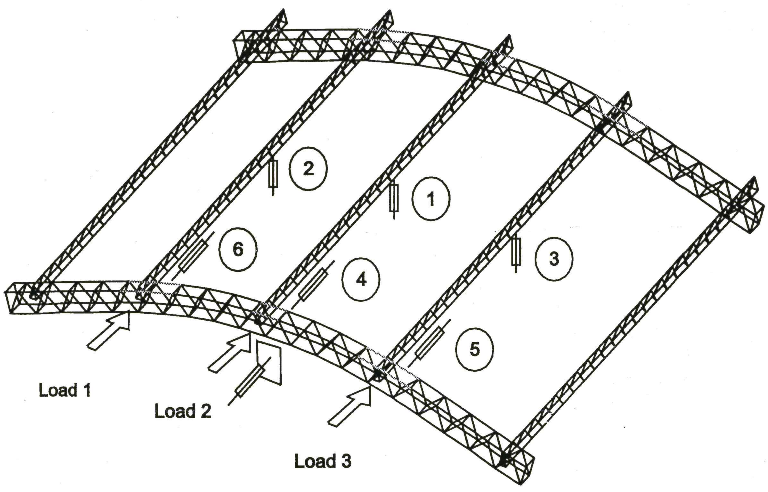

***Fig.6** Test setup for Lateral load application on Arch structure with proposed purlin.*

Numerical Simulation

A numerical simulation to predict the arch structure behavior considering the proposed purlin is performed using the Peruvian Standards for wind load NT-020 title 5, where the wind pressure is computed by:

$$P = 0{,}005\ C\ V^2 \qquad (1)$$

Where C is a shape factor, and V is the maximum wind velocity in Km/hr.

According equation (1) an incremental analysis is performed considering 98 N increment for lateral force. Wind velocity and applied pressure is computed taken a C value equal to 0,8 for pressure and 0,5 for suction. Table 1 shows the results where δh1 and δh3 are compute lateral horizontal displacement for purlin 1 and 3.

Table 1: *Numerical Simulation Results.*

F (N)	V(m/s)	P (Pa)	Fpressure (kN)	P (Pa)	Fsuction (kN)	dh1 (m)	dh3 (m)
98	981	48.80	0.225	30.50	0.141	0.009	0.005
196	13.87	97.60	0.451	61.00	0.282	0.013	0.009
294	16.99	146.41	0.676	91.50	0.423	0.017	0.013
392	19.62	195.21	0.902	122.00	0.564	0.021	0.017
490	21.93	244.01	1.127	152.51	0.705	0.025	0.021
980	31.02	488.02	2.255	305.01	1.409	0.046	0.041
1960	43.87	976.03	4.509	610.02	2.818	0.087	0.082
2940	53.73	1464.05	6.764	915.03	4.227	0.127	0.123

According with the historic velocity wind records in Perú, the maximum wind is 30,58 m/s, that means the extreme condition for lateral load on this structure is 980 N and 0,0456 m maximum displacement.

Fig. 7 Lateral load application.

Test Results

A monotonic test was carried out by the application of lateral load with three 19,6 kN hydraulic jacks as shows Fig. 7. The Fig. 8 presents the load displacement curves for each axis with purlin. It is possible to read from Fig. 8 for a lateral load level 1,47 kN the behavior is almost elastic. According with the numerical simulation an extreme wind load of 0,98 kN produce the peak wind velocity, therefore at this level the structure is still on the elastic range. Also after the 1,47 kN level a large displacement increment is produce on the structure. Because this large displacement, most of the sensors were setting out. The large deformation causes failure of the deck connectors (Fig. 9) at 1,96 kN load level and a lateral buckling on the arch occurs at the end of the test. However the structure could reach the 2,94 kN lateral load level with a maximum displacement 0,08 m. when arch buckling occurs (Fig. 10).

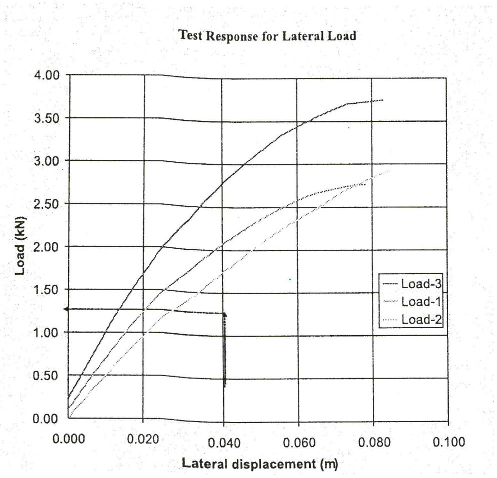

Fig. 8 Test Results for incremental lateral load.

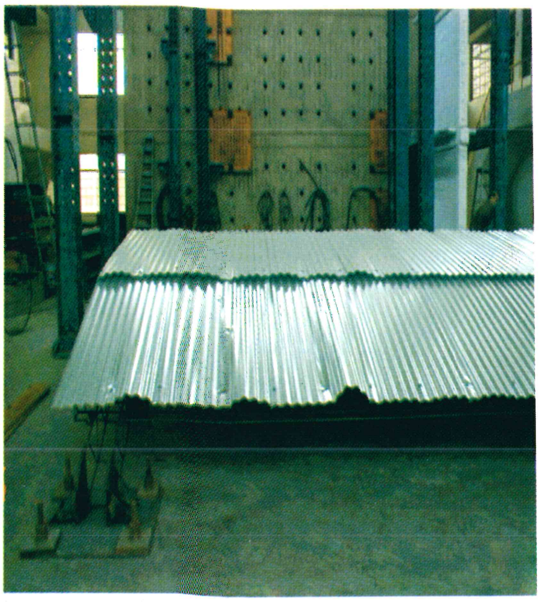

Fig. 9 Failure on deck connectors.

CONCLUSIONS

A loading test under extreme gravity load was performed over non conventional purlin pin supported on arch structure according with ASTM E-73. A gravity load level of the AISC LRFD standards, is about 40% below the experimental limit level. An elastic vertical displacement of 0,007 m was found for AISC requirements. A maximum vertical displacement 0,0157 m (L/360) was found for extreme gravity load.

A lateral loading test on full scale non braced arch – purlin was performed. The sequence of structure failure was the following: at 0,050 m deformation level, deck connector failure occurred for 1,96 kN load level (43,65 m/s wind velocity), at 0,08 m deformation level lateral buckling occurred in the arch for a 2,94 kN load level (53,65 m/s wind velocity). Therefore, considering the maximum wind velocity 30,8 m/s in Peruvian standards, the structure is still in elastic range and purlin showed satisfactory behavior.

Non failure of purlin–arch bolted joint occurred on the experiment. Therefore the purlin have enough strength to support lateral and gravity load requirements.

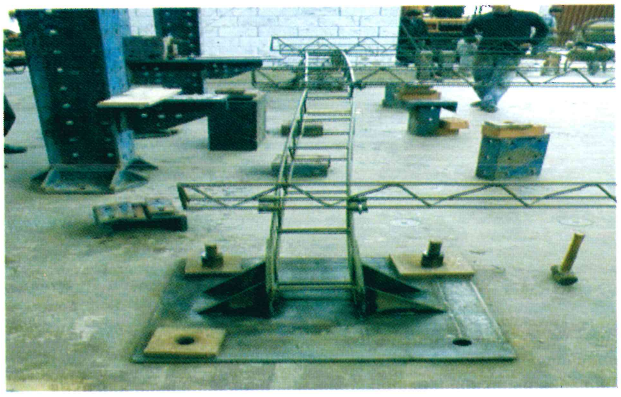

Fig. 10 Lateral Buckling on Arch.

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