



# ICCIFAM

Managing Assets and Infrastructure in the  
Chaotic Global Economic Competitiveness

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Facilities and Asset Management  
November 22-23, 2012, Padang - Indonesia



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ENGINEERING



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# PREFACE

Ladies and gentlemen,

First of all, I would like to say thank you for all involved and related parties, especially the steering committees who have spent their times and energy, and even their money for the success of this event: International Conference on Construction Industry, Facilities and Asset Management (ICCIFAM). We are also proud of the job done by the Faculty of Engineering, Andalas University who have succeeded to invited some other countries to participate in the event.

I would also say thank you for attending and participating for this program, especially all speakers who will contribute their views, thoughts, and ideas on the topic of this conference.

This event is held as a part of our programs in celebrating 56<sup>th</sup> anniversary of Andalas University. We plan to hold this event every year. I hope the conference is getting better over time. And many related parties related to the topic get involved and participated in this event. Even though, we would like to develop more to any discipline or field of studies existing in Andalas University.

Last but not least, thank you for your participation and contribution. And happy conference. Hope the conference generates positive inputs for all of us.



*Dr. H. Werry Dartta Taifur, SE, MA  
Rector of Andalas University*

## PREFACE

Ladies and gentlemen,

I am very happy for your coming to this conference room, to Faculty of Engineering, Andalas University in order to participate and contribute in this program: International Conference on Construction Industry, Facilities and Asset Management.

Again, I say: Welcome to the conference.

Beforehand, I would like to say thank you for all parties who have given supports and contribution, so that the program can be held. Especially, for the steering committees who prepare and arrange this event, I say thank you. Keep up your good job!

The theme of this conference is: Managing assets and infrastructure in the chaotic global economic competitiveness. So, we really hope your contribution in this conference in appropriate to the theme.

This event is held in order to promote, increase, and contribute to the scientific world and workplace. For scientific world, as we all know that science is developing over time, it makes the needs for fostering and discussing it. This event is one of the ways to foster and discuss it so that the development of science, especially in the field of construction industry, facilities and asset management can be done and achieved. For Faculty of Engineering, Andalas University, this program is one of our contributions to the world of science.

I hope, we all can participate in this program. And again, thank you. Let's spend our time in this conference.



*Prof. Dr.-Ing Hairul Abral  
Dean of Engineering Faculty,  
Andalas University*

## PREFACE

Ladies and gentlemen,

On this occasion, we would like to say thank you for inviting to and involving us in the beneficial program: International Conference on Construction Industry, Facilities and Asset Management (ICCIFAM). We are so proud to be part of and to be involved in this conference.

We are from West Sumatera Construction Services Development Board welcoming this program. That is why, we support, take part, and contribute as much as we can in order to hold that event. As an institute in the field of construction, we really need this event to development and increase our views and insights. This event is really valuable for us. There have been new developments in constructions in the world that we need so as to be able to apply in our daily job. In this conference, this moment we can have it. West Sumatera Construction Services Development Board really appreciates this event. So, we come and take part.

West Sumatera Construction Services Development Board hopes, through this event, we all can do and realize sustainable development as well as green development.

Thank you.



*Ir. Muhammad Dien Dt.  
Tumanggung  
Chairman of West Sumatera  
Construction Services Development  
Board (LPJK-P Sumbar)*



## PREFACE

Ladies and gentlemen,

This is an happy moment for all of us. We can be here together, talking and discussing about construction and facilities asset management. We say thank you for all parties who have supported and contributed in this event: International Conference on Construction Industry, Facilities and Asset Management (ICCIFAM).

The conference we hold, we had faced so many barriers and problems that one by one we can settle. Now, we are really happy, we can hold this event. We have been contacted by some experts and prospective participants from all over the countries, whether to be a speaker and participant. In addition to the local participants, the participants of the conference come from some countries in the world. They come, take part, and contribute their views and insights about construction industry, facilities and asset management.

We say thank you to sponsors, donators and all parties who have contributed and donated so that the event can be held. We realize we really need this event in order to achieve and do sustainable development. We all know that constructions and facilities asset management play an important role in achieving and realizing sustainable development. So, this event is crucial and urgent.

We hope, this conference is running as we all want. Thank you.



*Ir. Insannul Kamil, M. Eng, IPM  
Organizing Chairman*

# TABLE OF CONTENTS

<b>Preface from Rector of Andalas University</b> <i>Dr. H. Werry Darta Taifur, SE, MA</i>	i
<b>Preface from Dean of Engineering Faculty, Andalas University</b> <i>Prof. Dr-Ing. Hairul Abral</i>	ii
<b>Preface from Chairman of West Sumatèra Construction Services Development Board (LPJK-P Sumbar)</b> <i>Ir. Muhammad Dien Dt. Tumanggung</i>	iii
<b>Preface from Organizing Chairman</b> <i>Ir. Insannul Kamil, M. Eng, IPM</i>	iv
<b>Table of Content</b>	v

## PAPERS

1	<b>Occupiers As the Critical Stakeholder In Sustainable Buildings International Conference On Construction Industry, Asset And Facilities Management</b> <i>Richard Reed, Junaidah Jailani</i>	1
2	<b>Valuation Terminology Standardisation to Implement Mass Appraisal at Local Authorities for an Integrated Green Computing Environment in Malaysia</b> <i>Chitrakala Muthuveerappan, Buang Alias, Mohd Shafie</i>	13
3	<b>Post Occupancy Evaluation: The Need for Awareness and Knowledge for Continuous Improvement of Building Performance</b> <i>Izran Sarrazin Mohammad</i>	31
4	<b>A Successful and Substantial Nonstructural Energy Saving Initiative In the Public Transport Hub Building</b> <i>Mohd. Isa bin Sulaiman, Abdul Hakim bin Mohamed</i>	45
5	<b>Prediction of Freight Transportation In Lampung Province</b> <i>Tas'an Junaedi</i>	51
6	<b>Geological Control and Mitigation of Malino-Manipi Landslide, South Sulawesi Indonesia</b> <i>Busthan, A.M.Imran, L. Samang, M. Ramli</i>	61
7	<b>"Galodo" Padang 2012: Causes and Prevention</b> <i>Abdul Hakam, Febrin A Ismail, Fauzan</i>	67
8	<b>"COWAR" (Conservation of Water Resources): The Effort of Drought and Water Crisis Prevention In Brantas River Basin</b> <i>Anggun Sugiarti, Donny Harisuseno</i>	73
9	<b>The Impact of Remittance From International Migrants In Rural Area (Case Study: Bulupitu and Sepanjang Village, Malang Regency, Indonesia)</b> <i>Gunawan Prayitno</i>	83

10	<b>Renewable Energy from Waste Oil Palm Empty Fruit Bunches</b> <i>Wetri Febrina, Tatang Hernas Soerawidjaja, Ronny Purwadi</i>	89
11	<b>Lot Cripple Management Evaluation To Reduce The Number of Line Stop Using 8 Steps Approach and 7 Tools</b> <i>Mulki Siregar, Fitri Ayu Lovita</i>	95
12	<b>Implementation Comparison Analysis Method Junbiki with Kanban Reviewed by Method of Just In Time for Its Company Productivity</b> <i>Raihan, Afriani Lestari</i>	105
13	<b>Implementation of Agropolitan Approach in Malaysia: Preliminary Study at Pulau Banggi</b> <i>Yusof Ahmad, Eusoff Yendo Afgani, Hamid Saad</i>	115
14	<b>Design of Supply Chain Management (SCM) Palm Oil Production Flow In Web-Based</b> <i>Henny Yulius, Abulwafa Muhammad, Susi</i>	121
15	<b>Concrete Attribute of Culture on Kayik Public Place: When Simplicity Rules</b> <i>Eusoff Yendo Afgani, Mahmud Bin Muhammad Jusan, Aliyu Salisu Barau</i>	131
16	<b>Study the Impact of Knowledge Management Strategies on Firm Performance and Environmental Hostility as Moderator In Indonesian Manufacturing Firms</b> <i>Alizar Hasan</i>	137
17	<b>Analytical Method for Seismic Performance Evaluation of Infilled R/C Frames</b> <i>Maidiawati, Yasushi Sanada</i>	149
18	<b>Condition Index Based Maintenance and Rehabilitation Management</b> <i>Yervi Hesna</i>	159
19	<b>Used Container As A Temporary 'Public Toilet'</b> <i>I Putu Widjaja Thomas Brunner, R. Roni Gursala, Roy Marko Tinamnunan, David Hayatullah</i>	171
20	<b>Key Parameters In Lapping</b> <i>Ikhwan Arief</i>	183
21	<b>Artificial Rain Technology As An Alternative Increasing Sutami Reservoir Volume In Effort Tackling Drought Due To Global Climate Change</b> <i>Annisa Akalily, Donny Harisuseno</i>	189
22	<b>Fuzzy Multi-Objective Periodic Review Inventory Problem In A Dyadic Supply Chain System</b> <i>Dicky Fatrias, Yoshiaki Shimizu</i>	197
23	<b>Issues and Threats of Asset Management In Global Perspective</b> <i>Bambang Istijono</i>	203
24	<b>Feasibility of Tubular T-Joints As A Damage Controller for Roof Structures Under Loading</b> <i>Eka Satria, Shiro Kato</i>	211
25	<b>An Analysis of Heavy Equipment Supply Chain In Supporting Infrastructure Construction</b> <i>Togar M. Simatupang, Achmad F. Hendarman</i>	219
26	<b>Numerical Analysis Strategy for Solving the Large Scale and Complex Civil Engineering Structures Problems</b> <i>Jafril Tanjung, Makoto Kawamura, Harpito</i>	227



27	<b>Framework for Risk Allocation In PPP Infrastructure Development</b> <i>Susy Fatena Rostiyanti, Moch. Husnulloah Pangeran</i>	235
28	<b>Designing Maintenance Scorecard and Priority of KPI as Maintenance Performance Measurement Instrumen in PLTD (Diesel Power)</b> <i>Taufik, Vidya Ayuningtyas</i>	247
29	<b>Structural Analysis Program of Plane Frame with Visual Basic Language</b> <i>Agus Rivani, Nirmalawati</i>	259
30	<b>Computer Assisted Life Cycle Costing of Road Assets for Disaster Zone In Padang Indonesia</b> <i>Insannul Kamil, Buang Alias, Hakim Mohammed, Nilda Tri Putri, Dio P. Hasian</i>	269
31	<b>Performance Changes of Aerobic-Anoxic Membrane Bioreactor for Azo Dye Biodegradation Under Different Hydraulic Retention Time In Anoxic Tank</b> <i>Puti Sri Komala, Agus Jatnika Effendi, IG. Wenten, Wisjnuprpto</i>	277
32	<b>Life Cycle Costing of Road Assets In Disaster Zone (Case: Alai – By Pass Roads, Padang-Indonesia)</b> <i>Insannul Kamil, Buang Alias, Hakim Mohammed, Nilda Tri Putri, Dio P. Hasian</i>	283
33	<b>A Methodology to Evaluate Construction Project Using The Concept of Lean Construction</b> <i>Alfadhlani, Sarah</i>	289
34	<b>Flexural Crack Analysis In Reinforced Concrete Beams with Short Shear Span Length</b> <i>Rendy Thamrin, Noor Azlina Abdul Hamid, Zalipah Jamellodin, Muhammad Aminsyah, Riza Aryanti</i>	293
35	<b>A Study On the Application of Frequency Radio of Signal Tracker As A Base of Comparison of Channels of The Use of Operator In GSM Frequency of GSM 1800</b> <i>Neilcy. T. Mooniarsih, Fitri Imansyah, Youlanda</i>	301

# FEASIBILITY OF TUBULAR T-JOINTS AS A DAMAGE CONTROLLER FOR ROOF STRUCTURES UNDER LOADING

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## ABSTRACT

This paper is aimed to outline characteristics of tubular T-joints that were applied on a new type of two-way system for single layer lattice roof under influence of static and dynamics loads. The proposed roof is composed of two main arches, intersecting each other with welded T-joint struts to provide space for tensioning membranes. Two main characteristics of tubular T-joint were shown in this paper. The first is the nonlinear behaviour of the joints under repeated vertical loading and the second is under seismic horizontal loading. The interesting feature found after the first study is an ability of the system to make self-recovery after loading, since a large displacement occurred due to heavy vertical load almost vanish after unloading. While for the second study, at the strong earthquake condition, the yielding of the tubular T-joints can be used to absorb some amount of strain energy. Consequently, due to those characteristics, deformation of the arches as the main frames of the roof can be reduced and any heavy damages on the arches can be minimized.

**KEY WORDS:** Lattice Roof, Tubular T-Joints, Recovery System, Energy Absorber

## 1. INTRODUCTION

The two-way system for single layer lattice roofs is attractive to architects and engineers since such a system is beautiful in shape, light in weight and also systematic in construction. In the design steps, one of the important tasks is to secure sufficient safety against buckling. Recently, there are many accumulated researches of the stability of steel reticulated shells, however only a few of them have been developed in case of two-way system for single layer lattice roof (Yamashita, *et al.*, 2001; Kato *et al.*, 2005, 2006; Fujibayashi, *et al.*; 2006). Therefore, the buckling characteristics of these kinds of structures still need to be investigated.

This paper is actually an advanced study from several previous researches in investigating buckling behavior of a new type of two-way system for single layer lattice roof under vertical static loads such as snow loads (Kato *et al.*, 2008, and Satria, *et al.*, 2008a) and dynamic loads such as an earthquake (Satria, *et al.*, 2008b). The new model of roof is composed of

two main arches intersecting each other with T-joint struts in order to provide a space for tensioning membranes. This system adopts no diagonal bracing elements to avoid complications in construction therefore the global form become more simpler than any previous systems.

If in the previous papers, the design feasibility of the introduced roof system under static and dynamic loads have been detailly outlined, the present paper focuses on the effect of the tubular T-joints on the overall characteristics of the roof system under loadings. The characteristic is considered very beneficial in designing of roof structures especially in areas of high seismic level.

## 2. NUMERICAL MODEL OF ROOF STRUCTURES

### 2.1. Configuration of Roof Structure

As shown in Fig.1, the roof form is in two-way model and it is composed of a set of parallel arches, where each arch is connected through a

set of struts to the orthogonal arches. The surface of the roof is assumed like a curved shell, which is formed geometrically by rotating an arch of  $AOB$  with a radius  $R_z$  along the two same shaped arches of  $EAF$  and  $GBH$ . The radii of arches  $AOB$  and  $COD$  are  $R_x$  and  $R_z$  respectively. The total rise  $H$  is the sum of the rise,  $H_z$ , for the arch in the  $z$  direction, the length of the strut,  $h_i$ , and the diameter of the chord,  $D$ , or mathematically written as  $H=H_z+h_i+D$ . The length of each member along the arches  $AOB$  and  $COD$  might be an arbitrary. In Fig.1b, several parameters are also introduced. Firstly,  $h_i$  is assumed to be constant, 2500 mm. Secondly,  $l_0$  is the length of arch member for each division has been assumed to be constant of 6000 mm at the centre of the roof in  $x$  and  $z$  direction. The surface has two half open angles,  $\phi_x$  and  $\phi_z$ , respectively in the  $x$  and  $z$  directions. In this paper  $\phi_x$  and  $\phi_z$  are assumed  $30^\circ$  and  $25^\circ$ . Then, each arch is divided into  $n$  members,  $n$  being assumed as 10 in this study, and the total arc lengths,  $L_x$  and  $L_z$  are set just to be 60000 mm. Therefore, both radii of arches can be calculated through equations,  $R_x=n.l_0x/2\phi_x=57296$  mm and  $R_z=n.l_0z/2\phi_z=68755$  mm, and the difference,  $Z_0=R_z-(R_x-h_i)=13959$  mm using  $h_i=2500$  mm.

## 2.2. T-Joint Connection

Tubular T-joint is modeled by connecting arch member, with diameter  $D=318.5$  mm and thickness  $T=8$  mm, to strut member, with diameter  $d=216.3$  mm and thickness  $t=8$  mm. Both members are made of steel using modulus

of elasticity ( $E$ ) is  $205 \times 10^3$  N/mm<sup>2</sup> and yield stress ( $\sigma_y$ ) is 235 N/mm<sup>2</sup>. The rigidities strengths of the joints are separately calculated using nonlinear finite element technique, fully described later in Chapter 3.

## 2.3. Boundary Condition and Distribution of Load

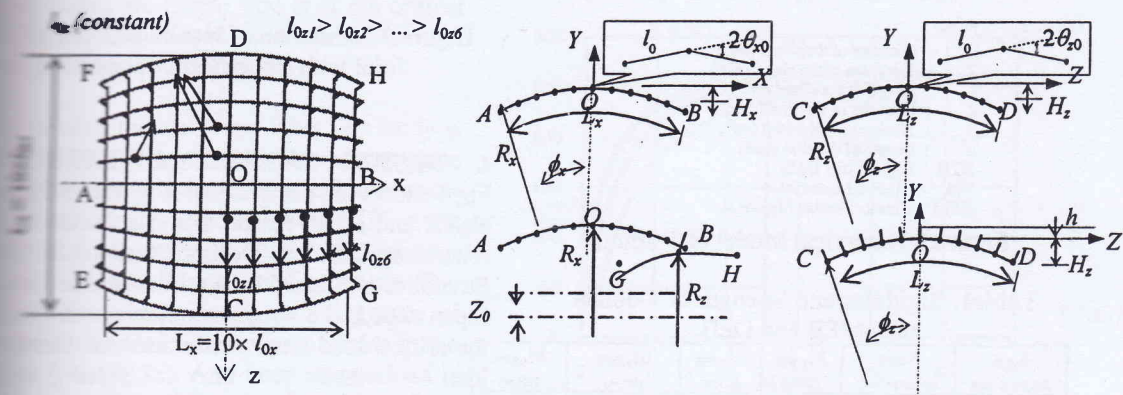
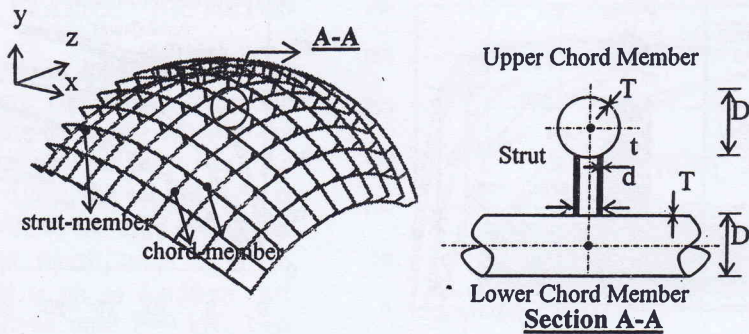
The roof is assumed to be initially subjected vertical dead load  $P_0$ , given at the upper and lower node of the strut members. Arches at the boundaries where all strut nodes have to be supported (restrained in the  $x$ ,  $y$  and  $z$  directions) at their upper and lower joints are exempted.

## 2.4. Geometrical Imperfections

Since effects of geometrical imperfections are large in case of single layer lattice roofs, the present study assumes a deformation distribution,  $W_{imp}(x,z)$ , for geometrical imperfections, based on the first buckling mode obtained by using FEM eigenvalue analysis for each model of lattice roof. Then normalization of deformation is done, so that the peak value of  $W_1(x,z)$  is set as 1.0 for the maximum deflection.  $W_{imp}(x,z)=w_{i0} \cdot W_1(x,z)$ ;  $w_{i0} = \pm \min(L_x, L_z) / 1000$  .. (1)

In this paper, the maximum amplitude of imperfection,  $w_{i0}$ , for the presented roof is assumed to be uniform, around 60 mm in the negative  $y$ -direction. This value is resulted from Eq. (1) with  $L_x$  is equal to  $L_z$  about 60000 mm.





**Figure.1(a)** Two-Way Single Layer Lattice Roof with Nodal Eccentricity (upper) configuration of Roof: Geometrical Model (lower-left) and Geometrical Parameters (lower-right)

**NUMERICAL MODEL OF TUBULAR JOINTS**

Following the procedure for modeling tubular joints developed by Cao et. al. (1997), the tubular joint model is successfully modeled, as seen in Figure 2. Both tubular members, brace and chord, are connected each other using welding which is modeled according to welding code which is given by AIJ (Architectural Institute of Japan, 1993). However, in this model, the welding part is not installed by a finite element model. Therefore, any failures due to stress concentration which are usually occurred in the welding part of tubular joint are not considered.

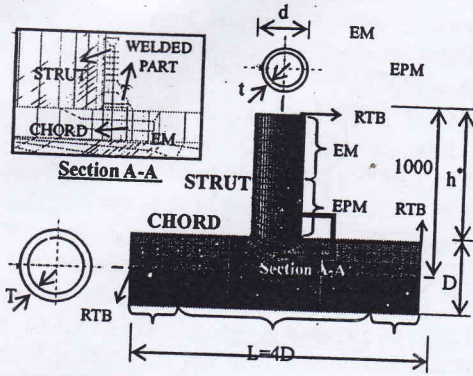
**Geometrical and Material Properties**

Tubular members, with geometrical properties mentioned in subchapter 2.2 are made using modulus of elasticity ( $E$ ) is  $2.1 \times 10^5 \text{ N/mm}^2$  and yield stress ( $\sigma_y$ ) is 235  $\text{N/mm}^2$ . The stress-strain relationship is modeled by bi-linear model with Von-Mises yield criterion, whereas plasticity condition is

represented by associated flow rule and isotropic hardening rule with hardening parameter ( $H$ ) of  $E/1000$ .

**3.2 Rigidities and Strength of T-Joint**

Rigidities and strengths of the tubular T-joint are determined by numerical calculation based on nonlinear FEM under three types of basic loading; in-plane bending (*IPB*), out-of-plane bending (*OPB*) and axial loading (*AXL*). Table 1 shows the results of calculation for all types of loading. However for axial loading case, the result is not shown in the table because of very small value of deformation given by this case.



- Note:
- D : Diameter of the chord (mm)
  - T : Thickness of the chord (mm)
  - L : Length of the chord (mm)
  - d : Diameter of the strut (mm)
  - t : Thickness of the strut (mm)
  - h : Length of the strut (mm)
  - RTB : Rigid Thin Body
  - EM : Elastic Material
  - EPM : Elasto-Plastic Material

Figure.2 Numerical Model of T-Joint

Table1. Rigidities and Strength of T-Joints under IPB and OPB.

$K_{IPB}$ (kN.m/10 <sup>3</sup> rad)	$K_{OPB}$ (kN.m/10 <sup>3</sup> rad)	$M_{y,IPB}$ (kN.m)	$M_{u,IPB}$ (kN.m)	$M_{y,OPB}$ (kN.m)	$M_{u,OPB}$ (kN.m)
33.71	10.01	323.0	337.0	221.0	247.0

Later, the rigidities and strengths given by Table.1 are used in all T-joints of the roof structure which is geometrically shown in Chapter 2.

### 3.3 Validity of Numerical Results

To check the validity of the numerical calculation (denoted by full lines), Fig. 3 shows its comparison to experimental results (denoted by dotted lines) given by some previous works. Akiyama's experiments are used to validate the results of in-plane bending and out-of-plane bending cases, while Makino's work (Akiyama, 1988) is used to validate the axial loading case. In general, all results show a good agreement between two approaches.

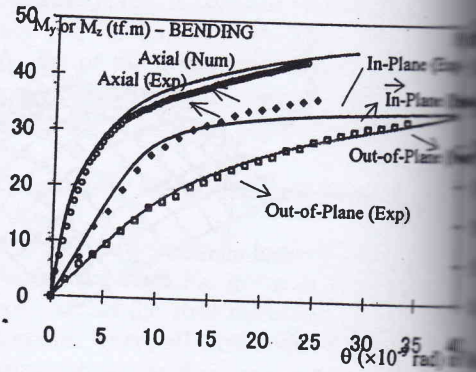


Figure.3 Validation of Nonlinear FEM of T-Joint with Experimental Results

### 4. DESIGN FEASIBILITY OF THE ROOF

Fig.4 shows the design feasibility the roof under elastic and elasto-plastic analysis. Based on the criteria specified in Design Standard for Steel Structures published by Architectural Institute of Japan 2002, the maximum displacement under the critical load from elastic analysis should be less than or equal to  $\delta_{max} = L_z/300 = 60000/300 = 200 \text{ mm}$ .

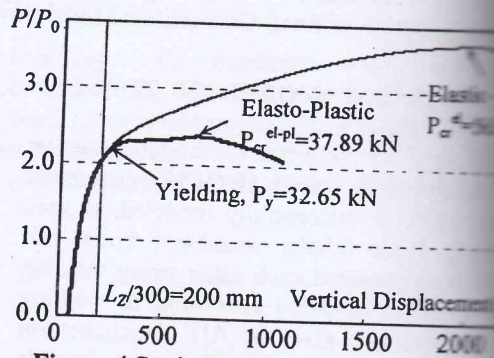


Figure.4 Static Response of Loading-Displacement

It means the load that gives  $\delta_{max} = 20 \text{ cm}$  can be notified as the critical load. This is found as  $P_{cr}/P_0 = 2.06$  leading  $P_{cr} = 31.1 \text{ kN/node}$  or in term of load intensity,  $P_{cr,design} = 2 \times 31.1 \text{ kN}/(6 \text{ m}^2) = 1.73 \text{ kN/m}^2$ .

According to its geometry, this roof practically can be used to support the dead load around  $0.85 \text{ kN/m}^2$  and additional vertical load like a snow load up to  $0.87 \text{ kN/m}^2$ . This value is corresponding to regions under moderate snow loads in Japan.



## CHARACTERISTIC OF T-JOINT UNDER A STATIC REPEATED LOADING

uniform snow loads ( $1 \text{ kN/m}^2$  per roof) are represented by giving (loading-unloading steps) to the. The first cycle is given until the  $\delta_1=10\text{cm}$ , the second cycle is followed by the third cycle is up to  $\delta_3=30\text{cm}$ , the fourth cycle is up to  $\delta_4=40\text{cm}$ , the last is up to  $\delta_5=50\text{cm}$ . All are given until  $P=0 \text{ kN}$ . Two are taken; first is at the critical and second is at the maximum ion point (Fig.5b).

feature found after this study is system for displacements since occurred due to heavy snow vanish after unloading [3], even the residual plastic deformation joint is smaller than  $10\text{cm}$ . The recovery is the fact that most of attribute to elastic strains in the (Fig.3a). And once an overload is parts at the ends of strut members plastically without any damage to

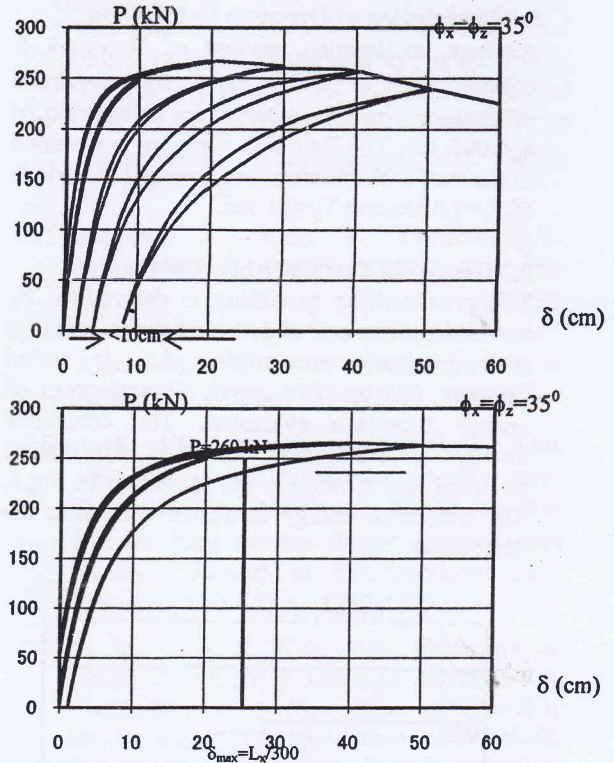


Figure.5 Static Responses of Roof Structure under Repeated Loading: (a) at the critical joint (top) (b) at the maximum vertical deflection joint (below)

## 6. CHARACTERISTIC OF T-JOINT UNDER A DYNAMIC LOADING

In term of dynamic loads such as earthquake motions, the plasticization of joint system can be considered is able to absorb energy due to the strong disturbances. The description below is used to justify this prediction under earthquake motion.

### 6.1 Earthquake Motion

El-CentroNS(1940) with 50 seconds duration and peak acceleration in range of  $100\text{cm/s}^2$  to  $1250\text{cm/s}^2$  are adopted for the horizontal seismic ground motion as presented in Fig. 4.

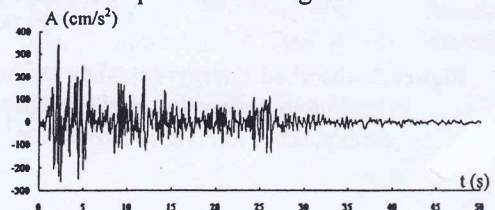


Figure. 4 Time history of El-CentroNS



### 6.2 Description of Dynamic Calculation

Average acceleration method of Newmark- $\beta$  scheme with  $\beta=1/4$  is used for numerical integration with time interval for calculation  $\Delta t$  is 0.005 sec. The Rayleigh damping is assumed to the roof with 2% damping constant at periods of  $T_1=1.5$  sec and  $T_2=0.1$  sec.

### 6.3 Results in Term of Absorbed Energy

Energy absorbing capability is determined by examining the roof under earthquake loadings with maximum acceleration  $A_{max}$  is varied between 100 to 1250  $cm/s^2$ . Several types of energy then are evaluated. The consumed energy is summation between kinematics, damping and strain energy, as shown in Fig.5. The kinematic energy is almost zero after the earthquake.

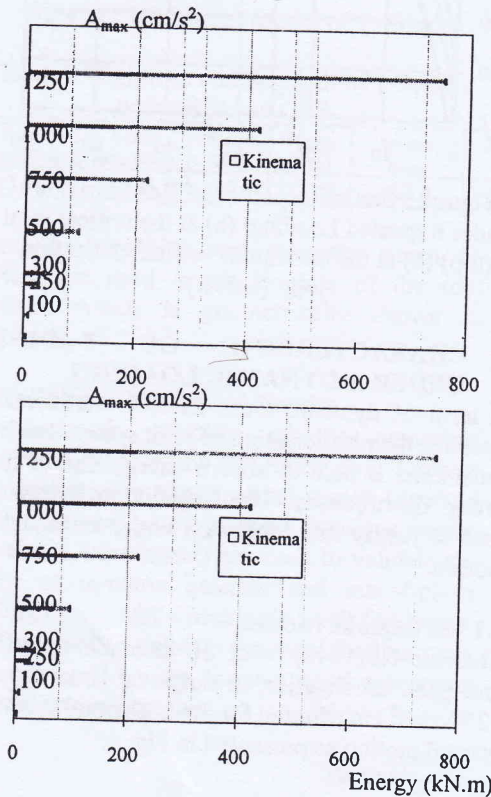


Figure.5 Absorbed Energy: (a) when earthquake is loading in x-direction, and (b) when earthquake is loading in z-direction

Table 2. Percentage of strain energy when earthquake is loading in x-direction (left)

$A_{max}$ ( $cm/s^2$ )	% Strain Energy (Loading in X-Direction)	
	Arch	Strut
100	89.0	11.0
250	89.0	11.0
300	85.6	14.4
500	14.6	85.4
750	3.7	96.3
1000	1.5	98.5
1250	0.8	99.2

Table 3. Percentage of strain energy when earthquake is loading in z-direction (right)

$A_{max}$ ( $cm/s^2$ )	% Strain Energy (Loading in Z-Direction)	
	Arch	Strut
100	89.0	11.0
250	89.0	11.0
300	84.4	15.6
500	10.9	89.1
750	2.1	97.9
1000	0.9	99.1
1250	0.5	99.5

Table 2 and 3 show the exact values and percentage of strain energy absorbed by the arches and struts during the earthquake in the x and z directions respectively. As a remark, it can be noticed that the struts mainly absorbed the strain energy when the structure is subjected to the earthquake with maximum input acceleration  $A_{max} \geq 500$   $cm/s^2$  while for ground motion  $A_{max} \leq 300$   $cm/s^2$  most of the strain energy is absorbed by the arches. This phenomenon may be explained with regards to the structures performance under earthquake loading as follows. During an earthquake shaking, the plasticity will first occur at the strut joints by yielding. However, the strain energy would be absorbed very well by the T-joints when yielding takes a place, reducing the possibility of some unexpected damages to the main arches. At the earthquake, strain energy is mainly absorbed by the main arches; but as the deformation is quite small in this case, the main arches would be in safe condition.

### 7. CONCLUSION

The present paper has investigated the characteristics of the tubular T-joints on the characteristics of the roof system

The presumptions assumed in the (1) the plan for the roofs is a size of  $L_x \times L_z$ , where  $L_x$  and  $L_z$  the rise is relatively shallow with the half open angle respectively directions, (3) the length of strut between orthogonal arches is the boundaries of roof at all pin supported, (5) the roof has imperfections of which peak  $= L_z/1000$ , and (6) the dead load is distributed.

important conclusions can be drawn as

feasible to be applied in of long span structures.

of using the T-joint struts against snow loads is that the residual deformation ( $\delta_0$ ) due to heavy loading compared to the maximum

The reason of this recovery is

most of the deformations attribute

struts in the structures, and once an

is given, some parts at the ends of

members are deformed plastically

damage to main arches

of using the T-joint struts against

is that the yielding of strut joints

capability to absorb some of

energy against severe earthquakes;

plastic residual deformations

after the dynamic loads are much

than maximum deformation during the

The results are very beneficial to

heavy damages to the main arches.

implies that the proposed roof has

damage-control characteristic against

earthquake motion.

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