Proposals to Create an Expert System to Predict Elastic-Plastic Behaviors of Single Layered Latticed Domes

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Abstract

The present author has been investigating the elastic-plastic buckling behaviors of single layered reticular domes since 1989. Such investigations were executed mainly by using a numerical simulation. Through the investigations, analytical results were accumulated and also there existed the problem that how to store them. One of the considerable solutions for it, is that making them to knowledge base being available in expert systems.

In the former study[2], the ultimate strengths and deformation modes are expressed as knowledge base by neural network and the prediction ability in the range where the analytical results are not existed, has been discussed. The preliminary discussion has also been taken in Ref.[1].

The aiming goal of the present study is to create an expert system which can predict the ultimate strength and buckling deformation pattern. The graphical user interface should be required to give an initial conditions of the objective dome to the system and to confirm the predicted results.

Thus, in the present paper, a simple and compact interface between users and the reasoning engine, based on Hyper Text Mark-up Language and World Wide Web CGI, will be introduced.

INTRODUCTION

An expert system has attracted engineers' attentions since it have the possibility to be one of efficient artificial systems which can solve complicated problems without human experts.

Trials to establish an expert system, have also been performed during about two decades, but in the structural designing field, they seem to be not grown up in terms of the quantity and quality in spite of that their availability has been emphasized.

Meanwhile, 'natural' or 'bio-computing' algorithms, including the neural network and the genetic algorithm, have been developed. These have an advantage against complicated problems which require searching large combinatorial spaces.

The present author has been simulating the elastic-plastic buckling behaviors of steel single-layered reticular domes through numerical analyses. The analyses have yielded ultimate strengths, displacement modes and stress distributions of specific steel reticular domes, under changing several parameters concerning with the geometry of the dome, peripheral conditions and external loading distributions. Such accumulated results could be utilized as a knowledge-base, from which available data can be induced to help structural designers.

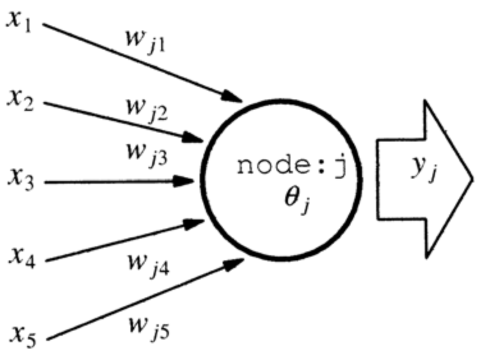
The neural network is one of the efficient ways to store such knowledge information. Furthermore, its interpolation ability is noticeable to attain the present purpose that is how to establish a compact expert system. Fundamental analyses with several parameters for the neural computation have also been performed to confirm the ability of the neural network as the reasoning engine for the expert system[1][2].
As the second stage of the trial, in the present paper, a simple interface between users and the reasoning engine, based on Hyper Text Mark-up Language and CGI on World Wide Web, will be introduced.

FUNDAMENTAL EQUATIONS FOR NEURAL NETWORK

The network geometry is determined by the numbers of hidden layers and nodes of each layer. Input parameters are given on the sensory units, and response units issue results that the engineer or designer wants to obtain. Between current and previous layer, the total input of j-th unit is expressed by

$$x_j = \sum_i y_i \cdot w_{ji} + \theta_j \qquad (1)$$

where subscripts j and i respectively mean j-th unit on a current layer and i-th unit on a previous layer. And y_i explains the output value from the i-th unit, w_{ji} are the connectivity strengths between j-th and i-th unit and θ_j is an offset (see also Figure 1).



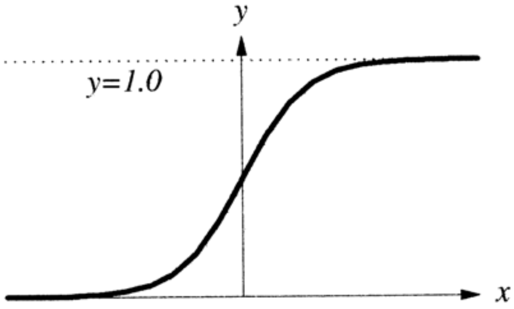


Figure 1 Input / output on node **Figure 2** Sigmoid Function

In the present network, the output from the j-th unit is assumed as

$$y_j = \frac{1}{\sqrt{1+e^{-x_j \cdot \mu_0}}} \qquad \text{(2)}$$

which is so-called as sigmoid function (Figure 2).

'Back-propagation' is adopted as the procedure to establish appropriate connectivity strengths for the network. The fundamentals are described as follows.
The total error of the network can be calculated from

$$E = \frac{1}{2}\sum_j (y_j - T_j)^2 \qquad \text{(3)}$$

where T_j is the desired state data on each response unit.

In the back-propagation, the connectivity strengths are modified by
the error gradient:

$$\frac{\partial E}{\partial w_{ji}} = (y_j - T_j)\cdot y_j(1-y_j)\cdot y_i \qquad \text{(4)}$$

The corrective gradient Δw_{ji} is calculated by the term whose amount is proportional to the accumulated $\partial E / \partial w_{ji}$.

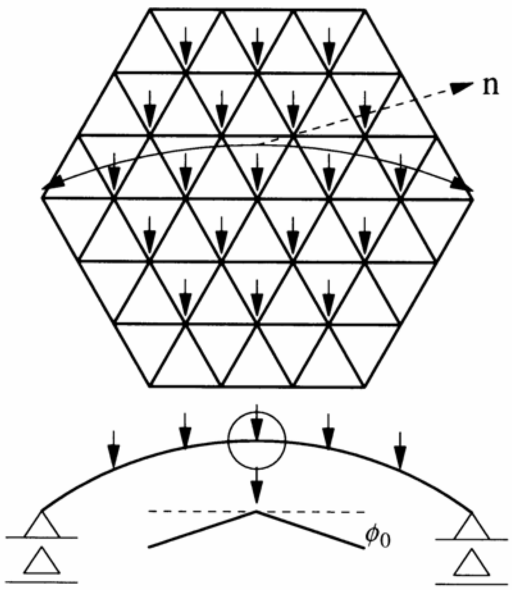
$$\Delta w_{ji} = -\alpha \frac{\partial E}{\partial w_{ji}}(t) + \Delta m \cdot \Delta w_{ji}(t-1) \qquad \text{(5)}$$

where (t) and (t-1) mean the current step and the previous step in the iterative procedure. The similar equation can also be applied on the corrective offset.

$$\Delta\theta_j = -\beta\frac{\partial E}{\partial w_{ji}}(t) + \Delta m \cdot \Delta\theta_j(t-1) \quad \ldots\ldots(6)$$

DESCRIPTIONS FOR ADOPTED SINGLE LAYERED RETICULAR DOME

The single layered reticular dome adopted in the present study, is composed of pipe members, subjected to uniformly distributed vertical loading, and has a three-way grid and hexagonal plan. The geometry and the material properties of constitutive pipe members are shown in Figure 3. When the semi-rigid connection is selected, the constitutive member is composed of pipe member whose ends are connected to the rigid ball by connector elements[4]. And the descriptions for elastic-plastic buckling analyses are found in Ref.[4].



n	2,4,6
λ	60, 96.21
ϕ_0	2, 2.5, 3, 3.5, 4°
connection	pin, semi-rigid, rigid
I_p, I_c	395.47, 11.46 cm^4
σ_y^p, σ_y^c	2.4, 2.7tf/cm^2
supports	pin, roller

Ic:moment of inertia of connector
Ip:moment of inertia of pipe
σ_y^p:yield stress of pipe
σ_y^c:yield stress of connector
$(1[tf] = 9.80665 \times 10^3 [N])$

Figure 3 Adopted Dome Geometry and Material Properties of Members

ADOPTED NEURAL NETWORK AS A REASONING ENGINE

Normalizing input/output parameters

Input data for the sensory units are normalized by considerable maximum values for each input as described in Table 1.

Table 1 Normalized Input Parameters

unit	1	2	3	4	5	6	7
input	$\frac{n}{20}$	$\frac{\lambda}{200}$	$\frac{\phi_0}{10}$	$\frac{\sigma_y^p}{10}$	$\frac{\sigma_y^c}{10}$	$\frac{I_c}{I_p}$	$\frac{pin\ support: 1}{roller\ support: 0}$

The ultimate strengths and deformation types obtained from elastic-plastic simulations, are given as desired state data corresponding to each set of input parameters.

The ultimate strength P_{cr} is normalized in the form of $P_{cr}(tf)/20$ and the ultimate deformation types are distinguished into member buckling (normalized data: 0), dimple buckling (normalized data: 0.5), and over-all buckling (normalized data: 1.0).
In the present study, 'member buckling' means that yielding of the middle part of the member is observed and then the dome would meet the ultimate strength. Also 'dimple buckling' denotes that the end parts of the compressive members around the dome periphery, are yielded and then the unit panel would deform in vertical direction, like dimples. And 'over-all buckling' comes out when the nodes around the dome apex deforms in vertical direction. Please note that above-classification is tentative.

Network geometry and parameters
The geometry of adopted network is illustrated in Figure 4 with the input and output parameters. The number of hidden layers is 3, and when the number of units on i-th hidden layer is denoted as n(i), n(1)=8, n(2)=6 and n(3)=4. Through parametric case studies[2], the parameters for the network have been selected as follows.
$\Delta m = 0.10$
$\alpha = 0.3$
$\mu_0 = 0.45$
without offset.

SIMPLE EXPERT SYSTEM

This chapter will introduce a so simple expert system with the above-mentioned reasoning engine based on the neural network. Since this expert system is still on a trial version,

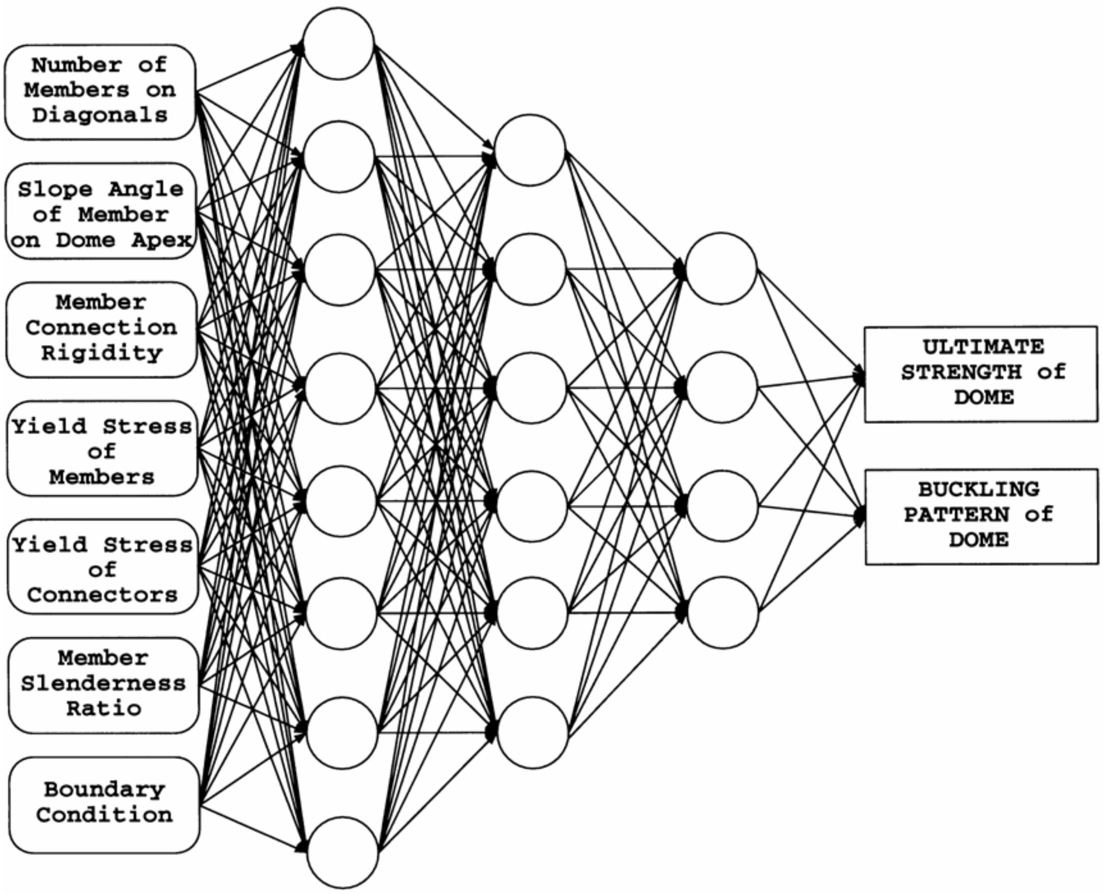


Figure 4 Adopted Neural Network and Input / Output Parameters

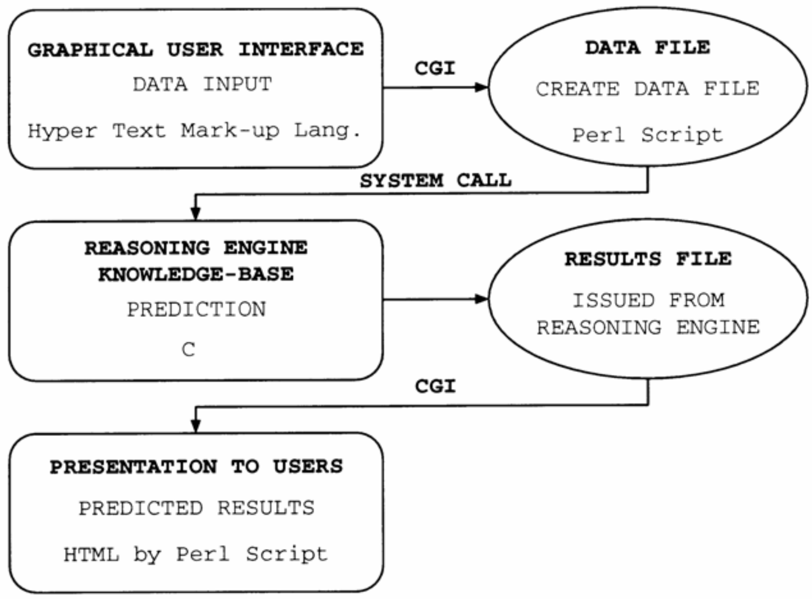


Figure 5 Constitution of The Present System

several error traps and issuing "WARNINGS" to users are not implemented. From view of non-limited platform, Hyper Text Mark-up Language (HTML) is adopted as a coding language to make the present expert system. The configure of the system is illustrated in Figure 5. The graphical user interface-unit is expressed by HTML.
Figure 6 shows the screen while the input parameters are selected. The parameters which can be selected, are similar to ones in Figure 3. The system could also help to know the meanings of the input parameters in detail when "explanation" is clicked.

When the parameter input and selection are completed, the interface-unit will transfer the input parameters to the file creation-unit to create the input data file being adaptable to the reasoning engine. The file creation-unit is coded by Perl script and uses UNIX system calls. It can be performed by CGI on World Wide Web (WWW) server.

The reasoning engine which has been coded by C, can predict the ultimate strength and deformation pattern with given input parameters. After that, the results file would be issued by the reasoning engine.

By involving the results file, the presentation-unit would show the input parameters and predicted values through CGI on WWW server. This unit has also been coded by Perl script.

EXECUTION EXAMPLE

The procedure to use the present simple expert system, is described by the screens indicating the parameters and pictures in Figures 6-9. Figure 6 shows the scene of preparing input parameters, and the explanations for them are indicated in Figure 7.

Example input parameters are;
(1)Member slenderness ration: 60, (2)Number of members on the diagonal lines: 6
(3)Slope angle of members on the dome apex: 3 degree,
(4)Yield stress of members: $2.4\,tf\ /cm^2$, (5)Yield stress of connectors: $2.4\,tf\ /cm^2$
(6)Connection rigidity: rigid, (7)Boundary condition: pin support

These can be selected within parameters of the table in Figure 3. For example, the slope angle of the members can be allowed as 3.25 degree, and the connection rigidity can be given as $I_c / I_p = 0.5$.

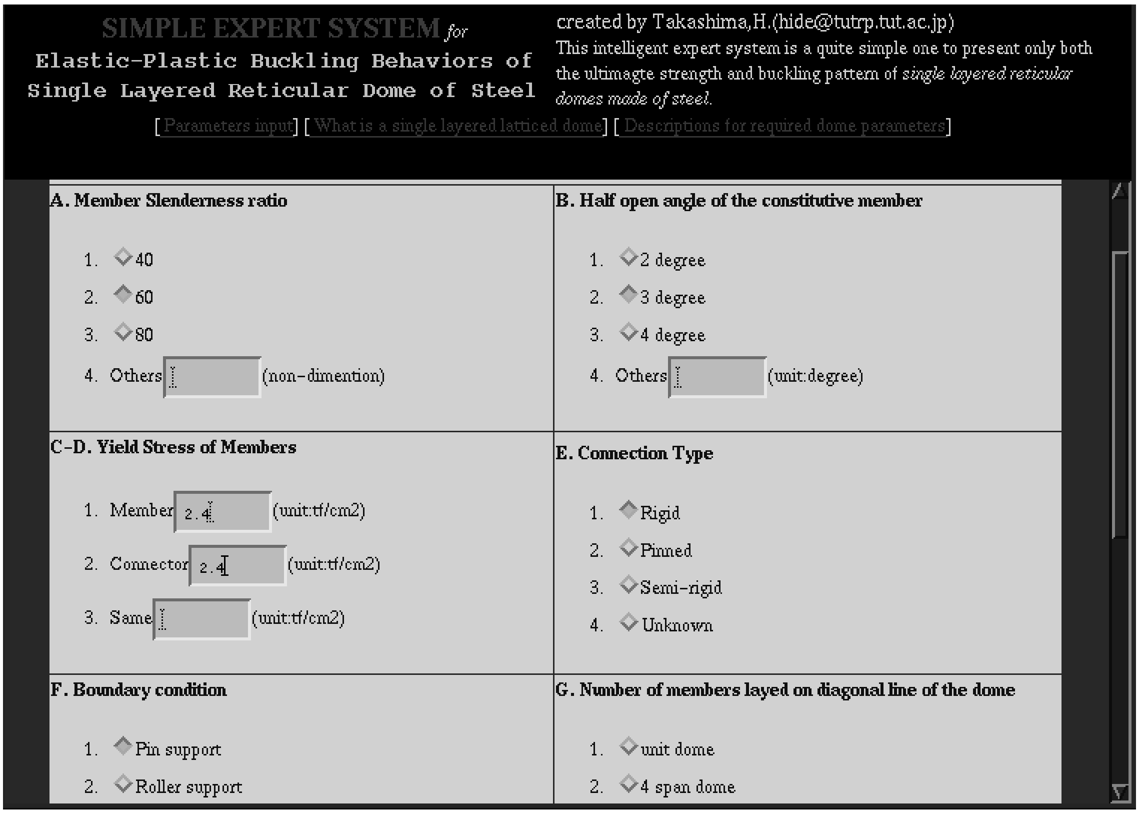


Figure 6 Parameters Input Screen by HTML

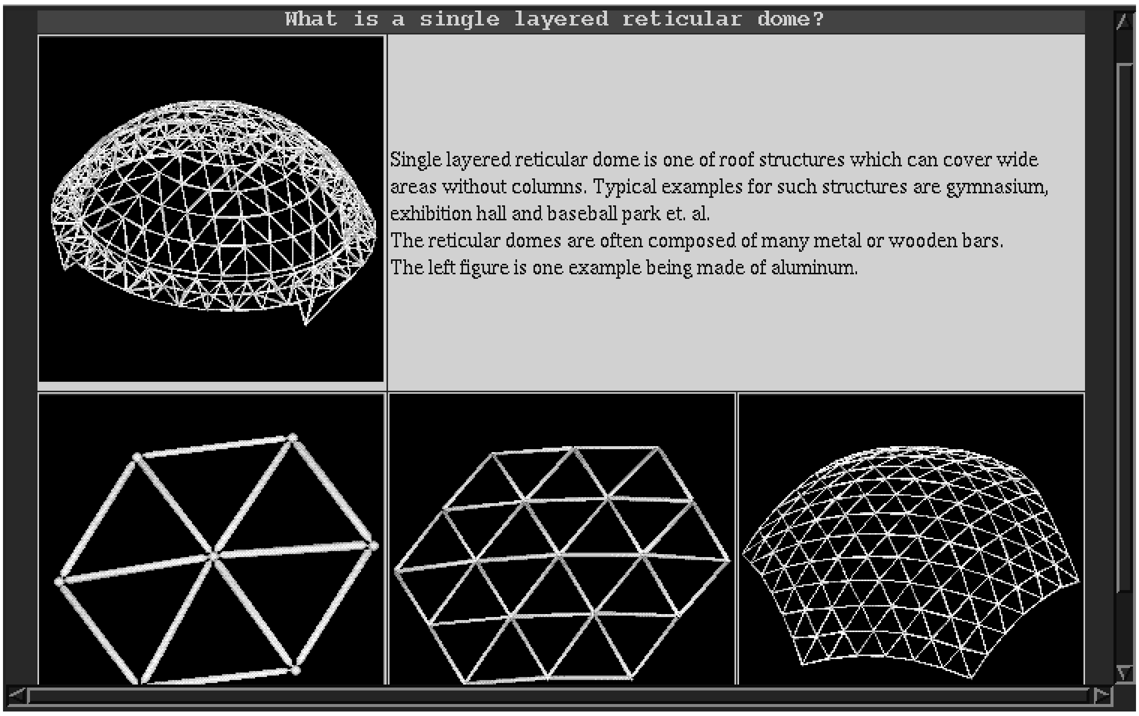


Figure 7 Indication of Explanation for Reticular Domes

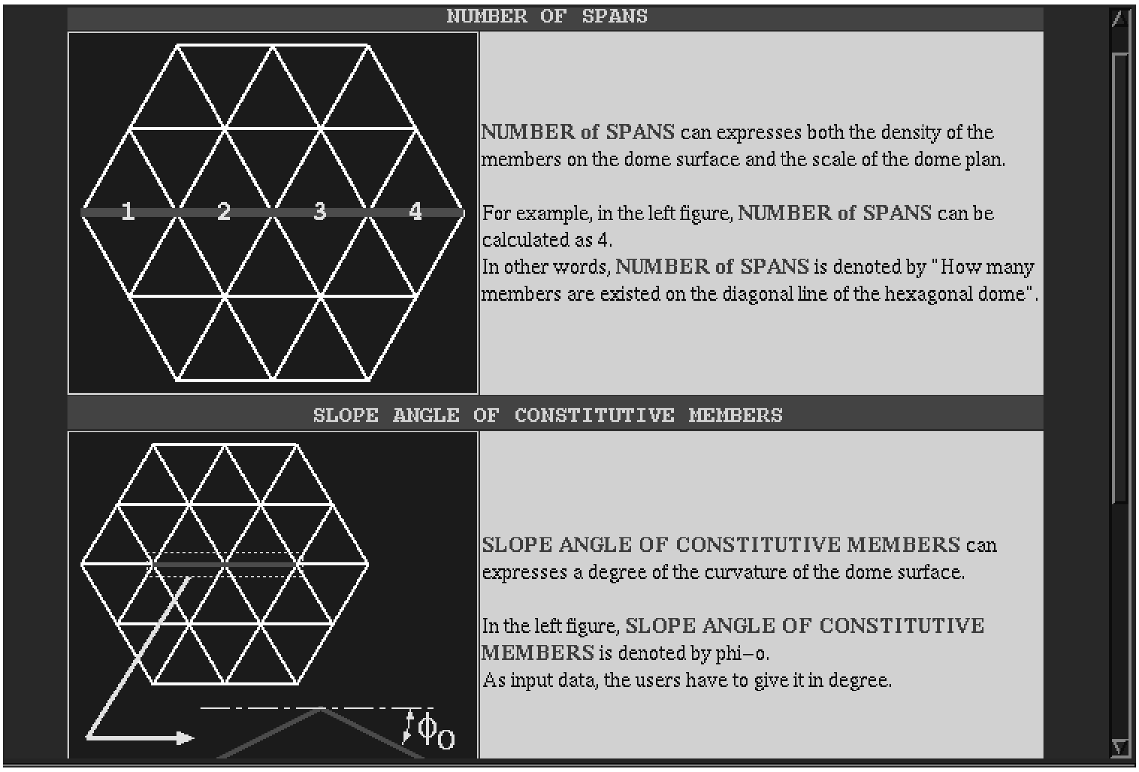


Figure 8 Explanations for Input Parameters

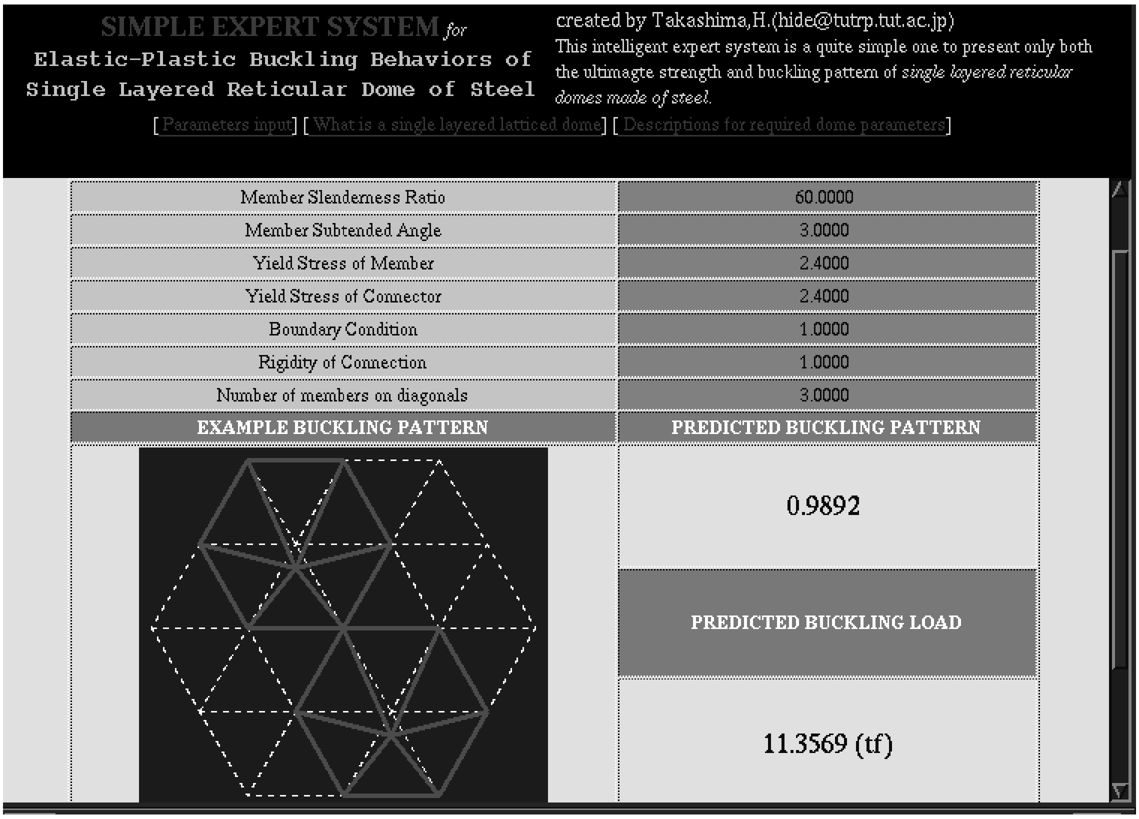


Figure 9 Presentation Screen for Predicted Results

Through the reasoning engine / knowledge-base, the ultimate strength and deformation pattern are indicated with the input parameters. Figure 9 shows the screen indicating the predicted results. The picture of the deformation pattern is an example and not true deformation. The buckling type is indicated as 0.99. It almost equals to 1.0 and denotes a dimple-type deformation. Meanwhile, the ultimate strength is predicted as $P_{cr} = 11.4tf$ per 1 nodal point.

CONCLUSION

This study has presented one example proposal to make an expert system involving reasoning engine based on a neural network. The introduced expert system does not have an enough ability to express the available data which are required by the designers.

By considering the practical design and other output formats, for example, giving exact deformation modes or which member to be yielded, more sound availability would be added to the present system.

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