

# Mapping Modeling Method of Tower Parking System Structure Based on Support Vector Machine

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**Abstract.** Aiming at the problem of large amount of calculation and solving inefficiency when using finite element software to analyze the “whole model” of complex space steel structure, the mapping model method built on the basis of SVM (Support Vector Machine) theory is proposed to reduce computation and enhance the computing efficiency. In this paper, taking tower parking system structure as the object, the mapping relationship is established among parking layers, conditions and the von Mises stress, maximum displacement which the system is subjected to. According to the mapping relationship, it can realize the prediction of von Mises stress and maximum displacement in different layers and conditions to avoid calculating “whole model”. The research shows that the maximum relative error of stress is 1.69% and the maximum relative error of displacement is 3.16% when compared results that predicted by SVM with results that calculated by finite element. At the same time, according to the comparison of mapping results which predicted by SVM and neural network, it comes the conclusion that results of SVM have a goodness of fit.

## Introduction

Along with the development of social economy and the demand of practical application, the style of large steel structure changes rapidly and more complex, so it has become one of the key technologies for the analysis of complex steel structure[1]. Because the majority of complex steel are statically indeterminate structures, so the model is simplified for a certain amount to calculated easily when the method of structural mechanics is used. However, the precision of calculation is just determined by the degree of simplification, it leads to the consequence of a low precision caused by the great difference between calculation model and actual model. The finite element software is adopted to build the model that has a small distortion, also it can reflect the real stress of structure very well and improve the precision of calculation. But because of the complex structure and massive parameters, the model leads to a long computing time, therefore, the efficiency is low relatively. In order to obtain a method that not only to improve the accuracy of large steel structure but also to decrease computation time, some scholars have tried to apply the mapping theory in it for seek a “compromise” method. Gao Youshan, Xu Gening [2,3] put the mapping method based on artificial neural network for modeling and optimization of large steel structure, proving the practicability and validity of this method. Mapping method based on SVM is proposed in this paper, which specifically for small sample data based on the statistical learning theory with the aid of

optimization methods to solve some problems in data mining, such the sample data can be trained to match an input to an output by introducing the kernel function, through training, the nonlinear mapping relationship between input and output can be created. Thus, the scientific and reasonable, less computing time and low distortion model is built which called “mapping model”.

As shown in figure 1, it takes complex steel structure of tower parking system as an object in this paper. Because every similar structure module is made up of two parking layers in tower parking system, taking structure module as units, first of all, parametric modeling is built by APDL language, then, constraints and loads are applied in it reasonably according actual condition for force analysis, finally, it can get the von Mises stress and maximum displacement of structure in different modules (i.e. parking layers) and conditions. In order to obtain the samples of SVM mapping modeling, module numbers and conditions can be as the input samples and von Mises stress and maximum displacement that calculated can be as the output samples, mapping model is built according to the samples training. Thus, corresponding stress and displacement of different modules and conditions can be predicted by the mapping model.



Fig.1 Steel structure of tower parking system

### Space “whole model” of tower parking system

APDL parametric language of large commercial software ANSYS is used to build and analyze the space “whole model” of tower parking system, the advantage is that you can modify various parameters of the parking system structure to obtain input samples and output samples that training required conveniently.

#### *Structural section selection and load analysis*

The steel structure of parking system is composed of column, beam and inclined brace. H-beam is selected for column and beam due to large bending stiffness, square steel tube is selected for inclined brace. The cross section parameters are shown in table 1.

Table1. Section parameters of tower parking system steel structure

Component	Column	Beam	Inclined brace
Species of steel	H-beam	H-beam	Square steel tube
Section parameters	300×300×10×15	200×200×8×12	120×6

Loads acted on the tower parking system structure are divided into concentrated loads and uniform loads. Among them, concentrated loads include vehicle and pallet weight, taking the module in to consideration, each unit has two parking layers and each layer has two storage spaces, therefore, each unit can be stored for 4 cars, the weight which was assigned to 8 columns and applied to the corresponding nodes; uniform loads include wind load[4] and the steel weight, similarly, they are applied to the corresponding nodes on average.

As shown in figure 2, taking 15 modules, 58 storage spaces as an example, the space “whole model” is established to conduct the force analysis. Since the “whole model” is established, meshing, loads applying and constraint control, the program of analysis and solving can be entered. By post-processing, von Mises stress and maximum displacement of steel structure are obtained.

### Structural force analysis under different conditions

Considering the effect of different load combinations to tower parking system, stress should be analyzed in different conditions, the aim is to find out the most unfavorable load combination for steel structure and make the von Mises stress and maximum displacement which produced in its role as the judgment of structure whether meet the strength, stiffness, and stability conditions. Different conditions mainly considered from the two aspects of the direction of wind and the number of parking, which divided into six situations, respectively: no-load (no parking), full load (all parking), limiting partial load (all vehicles parked in the same side) in the direction X of wind and no-load, full load, limiting partial load in the direction Y of wind.

Similarly, taking 15 modules, 58 storage of spaces tower parking system as an example, the structure of stress is analyzed under six kinds of conditions respectively; finally, it can obtain the corresponding von Mises stress and maximum displacement. The calculated results can be seen in table 2.

When the materials selected for Q235, the allowable stress is  $[\sigma] = 235 / 1.34 = 175 \text{MPa}$  and the allowable displacement is  $[d] = L / 1000 = 54850 / 1000 = 54.65 \text{mm}$ . As shown in table 2, the displacement reaches the allowable displacement firstly under the limiting partial load condition in X direction wind; therefore, taking the three conditions under X direction of wind as research object in the following, it creates the “mapping model” based on the training of input and output samples.

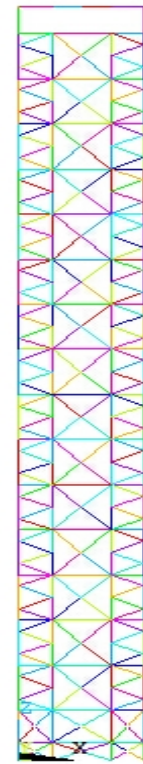


Fig.2 Space “whole model” of tower parking

Table2. Analysis results of tower parking system under different conditions

Structure characteristics	Wind load under X direction			Wind load under Y direction		
	No-load	Limiting partial load	Full load	No-load	Limiting partial load	Full load
Von Mises stress (MPa)	46.600	60.800	59.00	57.100	64.800	63.100
Displacement (mm)	45.253	58.736	45.09	39.903	42.013	39.775

### “Mapping model” of tower parking system

#### The mapping modeling theory based on SVM[5,6]

The form of structure about SVM is similar to artificial neural network; each node corresponds to a support vector. The structure is shown in figure 3, where,  $x^1 \sim x^d$  are input samples during training, representing the module of parking system and working condition;  $y$  is output sample, representing the corresponding stress or displacement with different modules and working conditions;  $K(x_i, x)$  is the kernel function of SVM, with a significant action, representing inner product operation of two points  $\Phi(x_i) \cdot \Phi(x_j)$  in high-dimensional Hilbert space.

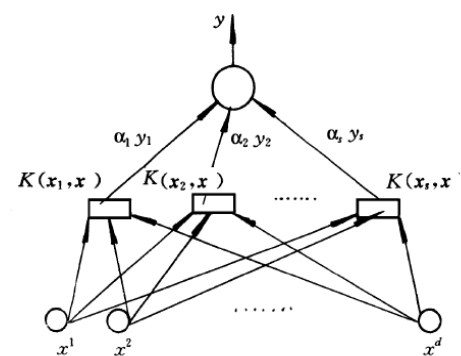


Fig.3 Structure diagram of SVM

As a kind of SVM, the character of  $\epsilon$ -support vector regression ( $\epsilon$ -SVR) is the introduction of  $\epsilon$ -insensitive loss function. The original optimization problem is built by choosing appropriate coefficient  $\epsilon$ .

$$\min_{w,b} \frac{1}{2} \|w\|^2 \quad (1)$$

$$\text{Constraint conditions: } \begin{cases} (w \cdot x_i) + b - y_i \leq \epsilon, i = 1, \mathbf{L}, l, \\ y_i - (w \cdot x_i) - b \leq \epsilon, i = 1, \mathbf{L}, l, \end{cases} \quad (2)$$

where  $x_i$  is the input data of sample set,  $y_i$  is the output data of sample set,  $w \in R^n$  is a mapping that low-dimensional input space translated into high-dimensional feature space,  $b \in R$ .

Linear regression function  $y = (\bar{w} \cdot x) + \bar{b}$  is constructed according to the solution  $(\bar{w}, \bar{b})$  of this problem.

However, formula (1) and formula (2) are not usually solved directly in practical application, but the optimization problem is constructed and solved by introducing the dual problem and appropriate kernel function.

$$\min_{a^{(i)} \in R^{2l}} \frac{1}{2} \sum_{i,j=1}^l (a_i^* - a_i)(a_j^* - a_j) K(x_i, x_j) + \epsilon \sum_{i=1}^l (a_i^* + a_i) - \sum_{i=1}^l y_i (a_i^* - a_i) \quad (3)$$

$$\text{Constraint conditions: } \begin{cases} \sum_{i=1}^l (a_i - a_i^*) = 0 \\ 0 \leq a_i, a_i^* \leq \frac{C}{l} i = 1, 2, \mathbf{L}, l \end{cases} \quad (4)$$

Therefore, it can obtain the optimal solution  $\bar{a} = (\bar{a}_1, \bar{a}_1^*, \mathbf{L}, \bar{a}_l, \bar{a}_l^*)^T$ ;

Where  $a_i, a_i^*$  are Lagrange multipliers,  $K(x_i, x_j)$  is kernel function,  $C$  is penalty coefficient.

Regression function is constructed based on the optimal solution  $\bar{a}$  :

$$f(x) = \sum_{i=1}^l (\bar{a}_i^* - \bar{a}_i) K(x_i, x) + \bar{b} \quad (5)$$

$$\bar{b} = y_i - \sum_{i=1}^l (\bar{a}_i^* - \bar{a}_i)(x_i \cdot x_j) + \epsilon \quad (6)$$

### *Mapping modeling process of tower parking system*

Firstly, with the optimization toolbox of MATLAB itself, the above theories are summarized and simplified then the MATLAB program is compiled based on MATLAB platform. Eventually it generates visual user interface for training and prediction conveniently. The procedures are as follows:

- 1) Appropriate training samples are selected. In order to make the prediction results as accurate as possible, the data of two groups of each end and two intermediate groups are selected in 15 module layers to make the module input, the working conditions of no-load, full load, limiting partial load are defined as 0, 1, 2 to make the condition input, the corresponding stress and displacement are calculated to make the output. The module layers remaining under different conditions are defined as the predicted data.
- 2) MATLAB is used to compile the program for solving optimization problems and create the SVR.m file.

- 3) First, the insensitive coefficient  $e$  , penalty coefficient  $C$  and kernel function are selected appropriately, then, by substitution of the data from 1) into the program which written in 2) , the optimal solution  $\bar{a}$  and the constant  $\bar{b}$  of regression function are obtained through training.
- 4) MATLAB is used to compile the program of regression function and create the Regression.m file.
- 5) As shown in figure 4, the graphical user interface about mapping modeling based on  $\epsilon$ -SVR of tower parking system structure is designed with the MATLAB software.
- 6) A part of data of training samples are tested to judge the quality of training results,  $e$  and  $C$  are justified properly which makes the results of training are optimal.
- 7) The rest of module layers under different conditions are input to obtain the corresponding stress and displacement.

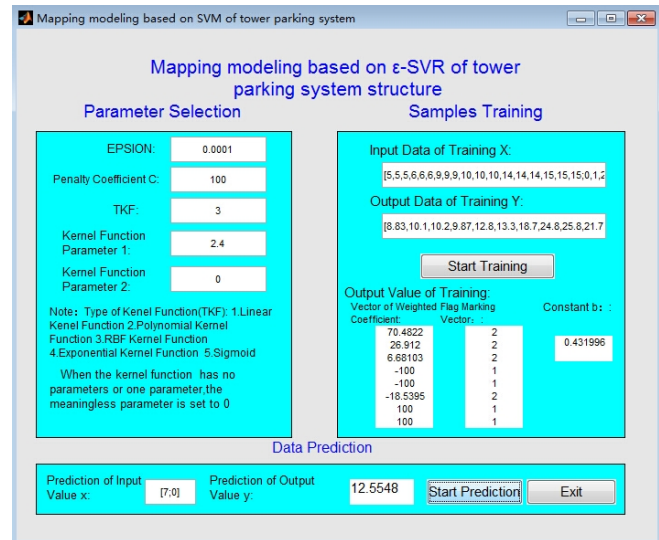


Fig.4 The mapping modeling user interface of parking system structure

#### The analysis of result

Mapping model is created by selecting the 18 groups of training data which constituted by 5, 6, 9, 10, 14, 15 module layers under three conditions respectively. By adjusting the parameters, the rest of module layers under different conditions are predicted to obtain the stress and displacement. The calculation results of “whole model” and “mapping model” as well as the relative error are shown in table 3.

Table3. Comparison of stress and displacement calculation results about tower parking system

Conditions	Module layers	“Whole model”		“Mapping model”		Relative error	
		Von Mises stress (MPa)	Displacement (mm)	Von Mises stress (MPa)	Displacement (mm)	Von Mises stress (MPa)	Displacement (mm)
No-load	7	12.6	4.358	12.5548	4.40433	0.36%	1.06%
	8	15.3	5.956	15.1066	6.10861	1.26%	2.26%
	11	25.5	15.449	25.7502	15.2004	0.98%	1.61%
	12	29.8	20.445	30.3027	20.3055	1.69%	0.68%
	13	34.9	26.973	35.3265	26.8745	1.22%	0.37%
Full load	7	16.3	4.318	16.2995	4.37047	0	1.22%
	8	20.1	5.904	20.0930	6.06187	0.03%	2.67%
	11	34.4	15.354	34.2927	15.1094	0.31%	1.59%
	12	39.6	20.334	39.9276	20.1975	0.83%	0.89%
	13	45.5	26.845	45.9620	26.7481	1.01%	0.36%
Limiting partial load	7	17.0	5.839	16.8513	5.96731	0.87%	2.20%
	8	21.0	8.243	20.8707	8.50358	0.62%	3.16%
	11	35.7	21.243	35.6762	21.2430	0.07%	0
	12	41.0	27.837	41.4685	28.0297	1.14%	0.69%
	13	47.1	36.230	47.6284	36.3748	1.12%	0.40%

As shown in table 3, compared the predicted results of “mapping model” with the results of “whole model” calculation of different modules and conditions, the maximum relative error of

stress is 1.69% and the maximum relative error of displacement is 3.16%, which satisfied the error requirement of 5% in engineering design. It is proved that results with calculated by the method of e-support vector regression machine has a high goodness of fit, at the same time, it can avoid the calculation of stress and displacement in all conditions and module layers by using “whole model” which reduced the amount of calculation.

### Comparison of mapping modeling method of SVM and neural network[7,8]

BP neural network is a multi-layer feed forward neural network based on error back-propagation algorithm, the core of BP algorithm is error propagation backward and error correction at the same time, then the every layer weights is modified to minimize the error signal until it meets the allowed error determination to achieve or approach the desired input, output mapping relationship.

The “mapping model” of tower parking system based on neural network is created to obtain the stress and displacement of different layers and conditions by selecting the same samples as above for training and predicting. The results are as illustrated in table 4.

Table4. The predicted results of mapping modeling based on neural network

Conditions	No-load					Full load		
Module layers	7	8	11	12	13	7	8	11
Von Mises stress (MPa)	12.3299	14.8012	25.2242	29.5463	34.7488	15.7391	20.3890	34.7190
Displacement (mm)	4.0198	5.8755	16.1302	21.0080	27.0660	4.4809	6.2713	14.2813

Conditions	Full load			Limiting partial load			
Module layers	12	13	7	8	11	12	13
Von Mises stress (MPa)	39.9996	45.6232	16.2558	20.8035	35.4503	40.4144	47.0409
Displacement (mm)	19.2784	26.6447	5.3292	8.1759	21.3603	27.1195	35.80596

In order to compare the predicted results of SVM and neural network more obviously, the 15 groups relative error of results which predicted by this two methods are contrasted as shown in figure 5 and figure 6.

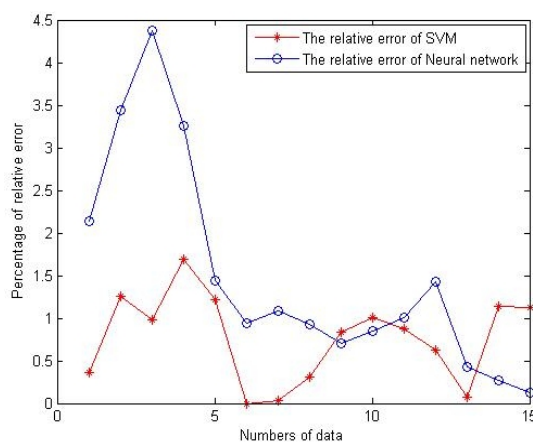


Fig.5 The relative error of results comparison chart of stress

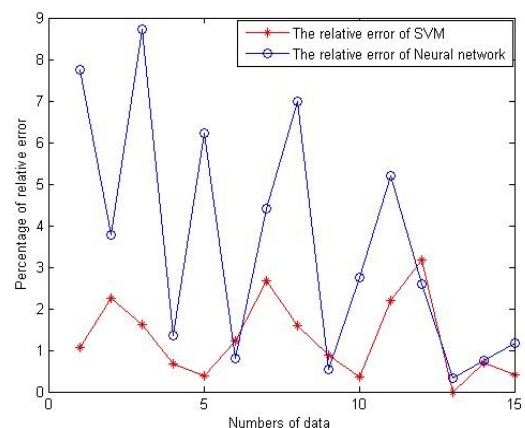


Fig.6 The relative error of results comparison chart of displacement

It can be seen that the predicted results of SVM have a less volatility and a high goodness of fit compared with the neural network, demonstrating the effectiveness of the SVM for a small sample of data during training from figure 5 and figure 6.



## Conclusions

- 1) The failure of the steel structure of tower parking system is the main unstable failure, then the strength failure, moreover, the harm brought by limit partial load is largest to structure relative to other forms of loads;
- 2) By using support vector machine (SVM) and through the training of small sample data for tower parking system, it can establish the “mapping model” by the mapping relationship acquired from input and output data, then, the corresponding stress and displacement of different module layers and conditions are predicted according to the model. Research shows that the relative error of model predicted results is very small compared with the finite element calculation, it is confirmed that the “mapping model” has a high goodness of fit and effectiveness in reducing the amount of calculation at the same time, so a new modeling method is put forward for steel structure design of tower parking system;
- 3) By comparing the predicted results based on SVM mapping model and neural network mapping model, the stress and displacement which predicted by SVM have a high goodness of fit. It highlights the superiority on the training of small sample data when using SVM;
- 4) The formula of kernel function, insensitive coefficient and penalty coefficient are selected reasonably when using the support vector regression machine. The size of  $e$  affects the quantity of support vector in SVM,  $C$  is too large or too small, the generalization ability will decline.

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