Estimation of Residual Stress in a Dissimilar Metal Welding Zone Using CSVR

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- Estimation of Residual Stress in a Dissimilar Metal Welding Zone Using CSVR

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Introduction

❖ ***Among the factors that have influence on structural fatigue life, residual stress is a critical factor that has an impact on the life of parts in operating NPPs.***

❖ ***Therefore, residual stress in welding of dissimilar metals at NPPs is estimated using CSVR as a method to keep the integrity of internal structures of NPPs in this study.***

Introduction

✓ Estimation of Residual Stress at Welding Zone

- **Residual stress** is a critical element in determining the integrity of parts and the lifetime of welded structures.

- Especially, the residual stress of a welding zone is an influential factor in generating **primary water stress corrosion cracking (PWSCC)**. Therefore, it is essential to accurately estimate the residual stress to inhibit the occurrence of PWSCC.

- The aim of this study is to estimate the residual stress of a welding zone under manifold welding conditions and known pipeline geometries by **cascaded support vector regression (CSVR)**. CSVR is a method that an SVR module is added and calculated iteratively before overffiting happens.

- ABAQUS code as a finite element analysis (FEA) method were utilized to anticipate residual stress generated by welding. Numerical modeling is an ideal method if its results can be verified with experimental results.

A Methodology for a Estimation of Residual Stress

❖ *In this study, residual stress of welding joint is estimated using CSVR.*

❖ *In the case that support vector machine is used for regression analysis, it is termed support vector regression.*

❖ *CSVR comprises of a calculation processes of serially connected SVR modules.*

❖ *In other words, all the SVR modules involve the same calculation process.*

A Methodology for a Estimation of Residual Stress

✓ Support Vector Regression

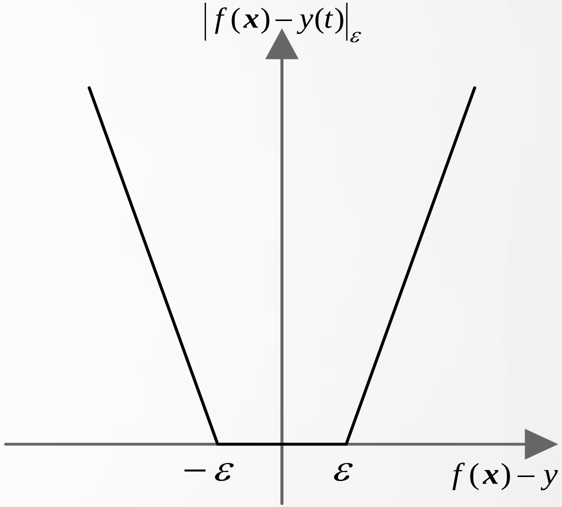
- The basic concept of the support vector regression (SVR) method is to **nonlinearly map the input data vector** into a higher dimensional characteristic space and it **performs a linear regression analysis in the higher dimensional characteristic space.**

$$\hat{y} = f(\mathbf{x}) = \sum_{t=1}^{N} w_t \phi_t(\mathbf{x}) + b = \mathbf{W}^T \boldsymbol{\Phi}(\mathbf{x}) + b$$

- The parameters $\boldsymbol{W}$ and b are calculated by minimizing the regularized risk function.

$$R(\mathbf{W}) = \frac{1}{2}\mathbf{W}^T\mathbf{W} + \mu \sum_{t=1}^{N} \left| f(\mathbf{x}(t)) - y(t) \right|_{\varepsilon}$$

$$\left| f(\mathbf{x}(t)) - y(t) \right|_{\varepsilon} = \begin{cases} 0 & \text{if } \left| f(\mathbf{x}(t)) - y(t) \right| < \varepsilon \\ \left| f(\mathbf{x}(t)) - y(t) \right| - \varepsilon & \text{otherwise} \end{cases}$$



A Methodology for a Estimation of Residual Stress

✓ Support Vector Regression

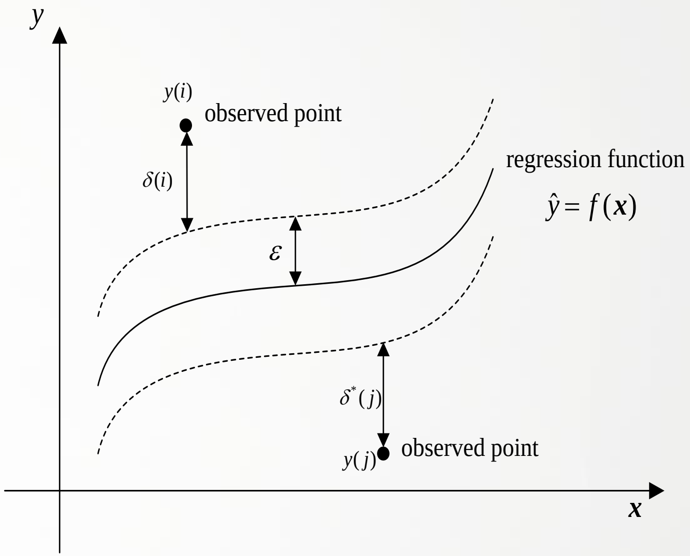
- The regularized risk function is changed into a constrained risk function.

$$R(\boldsymbol{W}, \Delta, \Delta^*) = \frac{1}{2}\boldsymbol{W}^T\boldsymbol{W} + \mu\sum_{t=1}^{N}\left(\delta(t)+\delta^*(t)\right)$$

$$\text{constraints}\begin{cases} y(t) - \boldsymbol{W}^T\boldsymbol{\Phi}(\boldsymbol{x}) - b \le \varepsilon + \delta(t), & t = 1, 2, \cdots, N \\ \boldsymbol{W}^T\boldsymbol{\Phi}(\boldsymbol{x}) + b - y(t) \le \varepsilon + \delta^*(t), & t = 1, 2, \cdots, N \\ \delta(t),\ \ \delta^*(t) \ge 0, & t = 1, 2, \cdots, N \end{cases}$$

- Finally, **SVR function** becomes

$$\hat{y} = f(\boldsymbol{x}) = \sum_{t=1}^{N}\left(\alpha_t - \alpha_t^*\right)K\left(\boldsymbol{x}, \boldsymbol{x}(t)\right) + b$$



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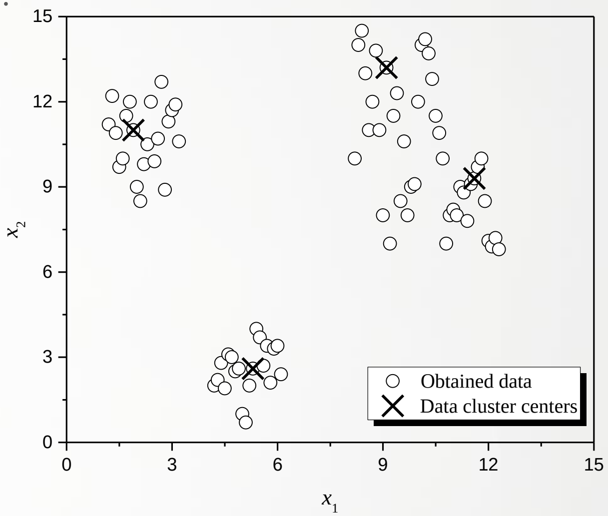
A Methodology for a Estimation of Residual Stress

✓ Subtractive Clustering

- The informative data that will train the SVR model are selected by **subtractive clustering (SC)** scheme in the present study.
  It is important to **select informative learning data** to increase the learning efficiency.



- It is expected that the learning data have a lot of clusters
  and the data at these cluster centers are more informative than adjacent data.

- These cluster centers are determined by using a SC scheme.
  The first cluster center is established at a point with the highest potential.
  The potential value of every input data point is calculated.

$$P_1(t)=\sum_{j=1}^{N} e^{-4\|\mathbf{x}(t)-\mathbf{x}(j)\|^2/r_\alpha^2},\quad t=1,2,\cdots,N$$

- **The data points near the pre-selected cluster center will have reduced potential.**
  The data point with the highest revised potential is selected as the next cluster center, when all data potentials are revised.

$$P_{i+1}(t)=P_i(t)-P_i^* e^{-4\|\mathbf{x}(t)-\mathbf{x}_i^*\|^2/r_\beta^2},\quad t=1,2,\ldots,N$$

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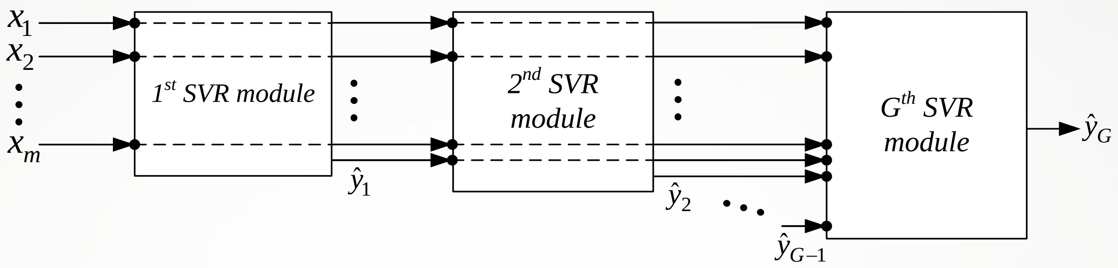
A Methodology for a Estimation of Residual Stress

✓ Cascaded Support Vector Regression



- In this study, **a cascaded structure connected in series** was applied to the SVR models.
- These the cascaded support vector regression (CSVR) model **comprise more than two SVR modules,** and **the results of the preceding SVR module are transferred to the next module**.
- The proposed CSVR model was **continually trained at each SVR module**. Thus, this process enabled the CSVR model to exhibit good performance.
- An excessive increase in the number of SVR modules could cause an **overfitting problem** in the CSVR model.

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A Methodology for a Estimation of Residual Stress

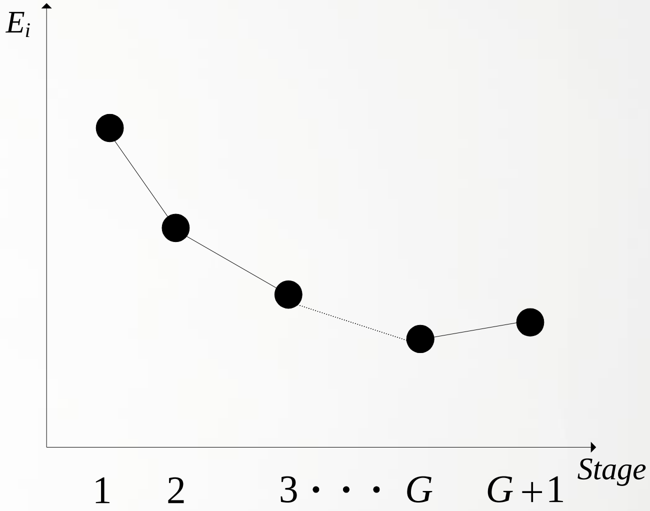
✓ Overfitting Problem

- There are three data sets such as the learning data, verification data, and test data used for the CSVR model, respectively.

- The **verification data set was used to prevent the overfitting problem** by limiting the number of serially connected SVR modules.

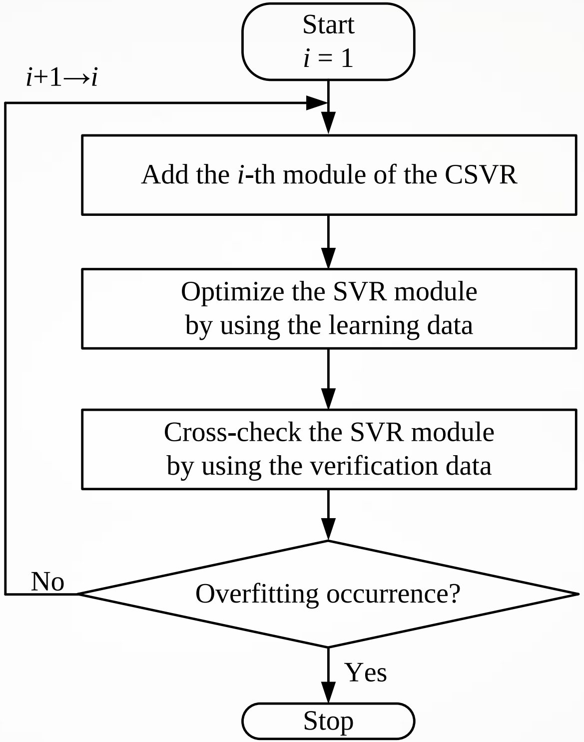
- An index to evaluate the occurrence of an overfitting problem at the *i*-th module is expressed as **the sum of the squared errors** for the verification data, as follows:

$$E_i = \sum_{t=1}^{N_V} \left(y(t) - \hat{y}_i(t) \right)^2$$



A Methodology for a Estimation of Residual Stress

✓ Development Procedure for the CSVR Model



Estimation Results Using CSVR

❖ *In order to develop the CSVR models, the residual stress data must be provided.*

❖ *An finite element analysis (FEA) method to analyze the residual stress of a welding zone was developed, and parametric FEAs were conducted using the ABAQUS code.*

❖ *It is shown that the trained CSVR can accurately estimate welding residual stress.*

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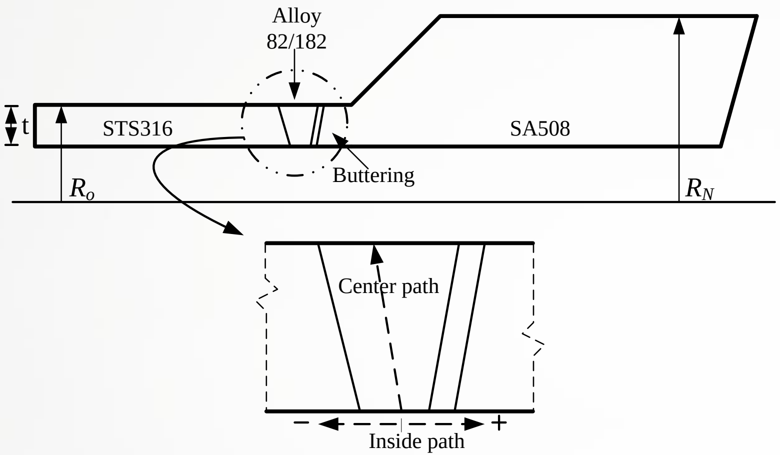
Estimation Results Using CSVR

✓ Data Acquisition

- A welding zone of dissimilar metals and the prediction paths in the welding zone for data acquisition.



Shape of the pipeline			End section constraint	Heat input, H (kJ/s)	Weld metal stress (MPa)
R_o (mm)	R_N (mm)	R_o/t		Pass 1; others	
205.6	300.10	4.8778	Restrained Free	0.49764; 1.2690 0.55985; 1.4277 0.62205; 1.5863 0.68426; 1.7449 0.74646; 1.9036	192.33 203.06 213.70 224.38 235.07
205.6	271.75	6.8763			
205.6	256.80	8.8735			

- Welding residual stress was calculated at 21 locations along each path.

- A total number of 6300 residual stress data were obtained from FEAs and used to develop the CSVR model.

Estimation Results Using CSVR

✓ Application Results

- Performance of the CSVR model in estimating the residual stress of a welding zone (**inside path**).

Constraint of end section	No. of SVR modules	Data type	No. of data points	RMS error (%)	Relative max. error (%)
Restrained	4	Learning	1250	3.574	53.641
		Verification	260	1.362	5.793
		Test	65	1.484	7.840
		Development	1250+260	3.301	53.641
Free	10	Learning	1250	2.839	27.804
		Verification	260	2.780	15.255
		Test	65	2.519	9.296
		Development	1250+260	2.829	27.804

- Performance of the CSVR model in estimating the residual stress of a welding zone (**center path**).

Constraint of end section	No. of SVR modules	Data type	No. of data points	RMS error (%)	Relative max. error (%)
Restrained	11	Learning	1250	0.276	2.892
		Verification	260	1.650	11.211
		Test	65	1.041	3.406
		Development	1250+260	0.729	11.211
Free	5	Learning	1250	1.339	24.936
		Verification	260	0.988	3.610
		Test	65	0.980	2.695
		Development	1250+260	1.285	24.936

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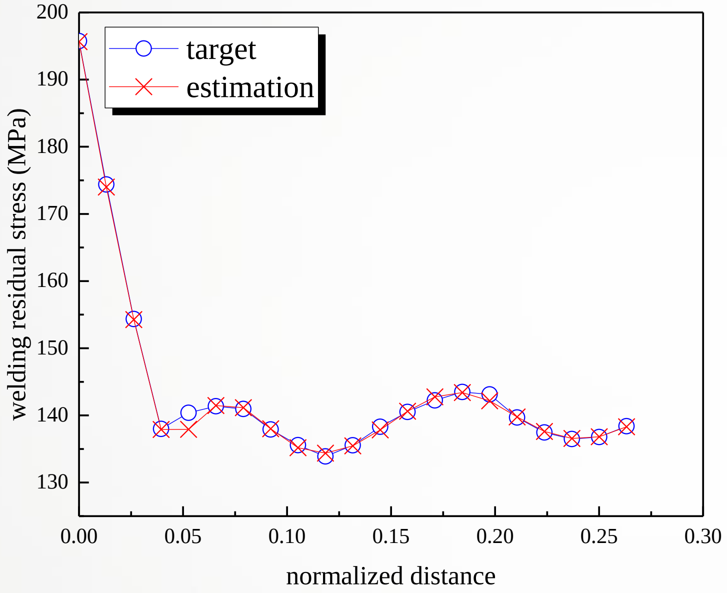
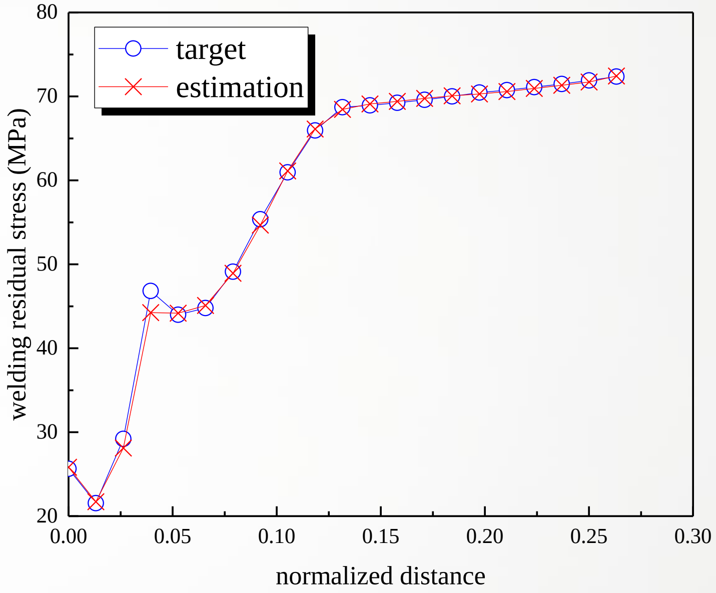
Estimation Results Using CSVR

✓ Application Results

- Target and estimation residual stress of a welding zone under a **specific welding conditions** using the CSVR (**inside path**).



(a) Restrained constraint

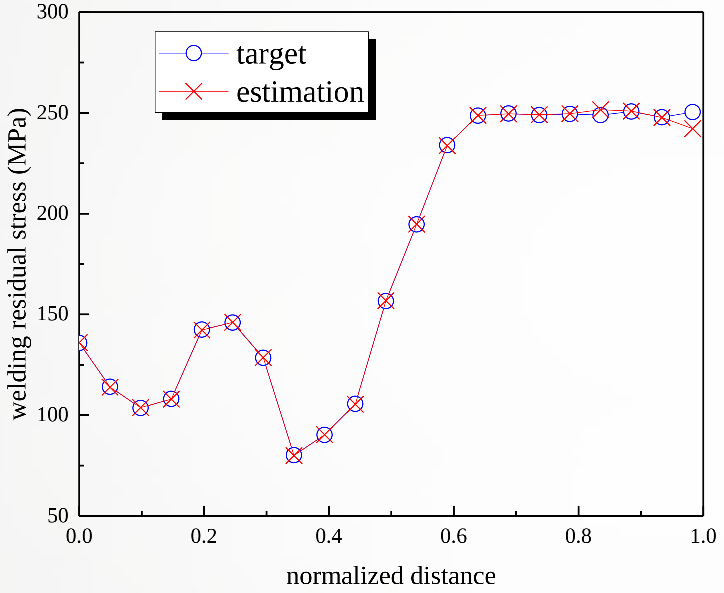


(b) Free constraint

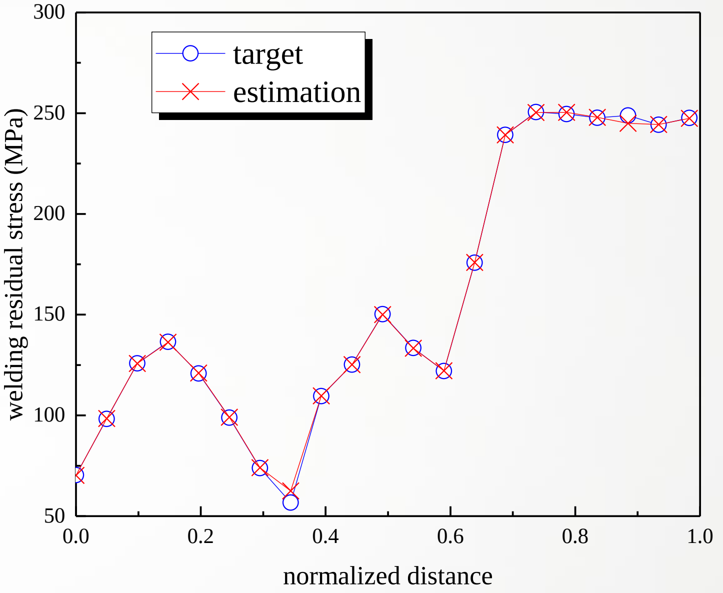
Estimation Results Using CSVR

✓ Application Results

- Target and estimation residual stress of a welding zone under a **specific welding conditions** using the CSVR (**center path**).



(a) Restrained constraint

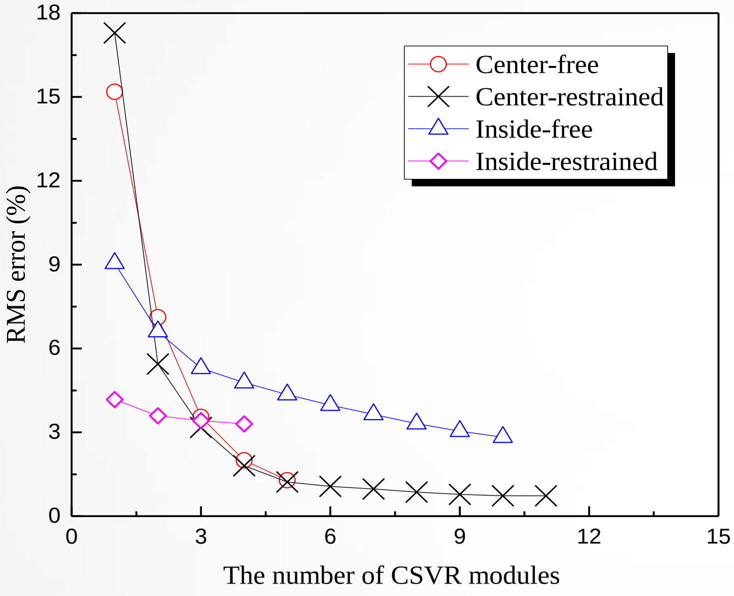


(b) Free constraint

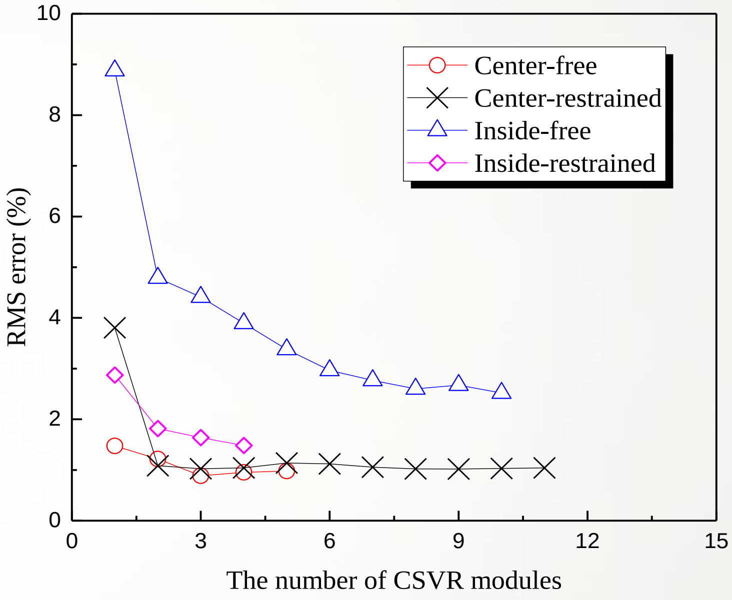
Estimation Results Using CSVR

✓ Application Results

- RMS error for the data versus the number of CSVR modules based on each path under the **whole set of welding conditions**.



(a) Development data



(b) Test data

Conclusions

❖ ***The proposed CSVR model can be considered as an outstanding model estimating the welding residual stress.***

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Conclusions

✓ Estimation of Residual Stress in a Dissimilar Metal Welding Zone Using CSVR

- In this study, residual stress of a dissimilar metal weld zone, which is susceptible to PWSCC, is estimated using SVR in cascaded structure.

- The welding residual stress data for training the CSVR model is gained from using ABAQUS code as a FEA model.

- The SVR model is efficiently trained using the informative data gained using SC scheme.
  The verification data set except the learning data set is used to prevent the overfitting problem in iteratively learning with cascaded structure.

- The CSVR performances according to two welding paths under each constraint show **1 to 3% RMS errors**.

- Consequently, the CSVR used in the present study is expected to estimate the welding residual stress of dissimilar metal.

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Questions & Answers

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Do You Have
Any Questions?

Thank you