SUBSPACE IDENTIFICATION USING N4SID METHODS APPLIED TO MODEL CONCRETE CHIMNEY

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ABSTRACT:

This article describes a new structural identification tool to define the structure of the modal characteristics have been proposed. N4SID abbreviation means "Numerical algorithms for Subspace State Space System Identification". In the SI (System Identification) of structure dynamics area area, N4SID has been used very frequently recently. The aim of N4SID is the determining of a mathematical model of a real or model structure.Thus, a model is formed about the reactions of the structures to different inputs. The model structure is created as an input and placed on the shaking table for output. After the acceleration responses are collected from the existing sensors, the data obtained through the Matlab SI (System Identification) toolbox are processed. Finally, Matrices A, B, C, D, K are obtained. For this purpose, analytical and laboratory studies to illustrate the effectiveness of N4SID evaluated. Concrete chimney sample was used as a model. Results demonstrated that fit to estimation data was 99,72 % and it can be concluded that N4SID system identification method is very efficient and accurate in identifying mathematical model of Model Concrete Chimney.

KEYWORDS: N4SID, SSI, Modal Data Identification, Mathematical Model, Model Concrete Chimney

INTRODUCTION:

Many of the structures in areas with earthquake hazard suffer from various types of destruction caused by seismic loads. In such an earthquake, parts (especially columns) of building structures are damaged. On the other hand, especially given the performance of such buildings under seismic formation, there is a great need to strengthen the pillars even without changing the building masses; this clearly shows that it is necessary to investigate the link between technical repair or strengthening procedures and column capacity. In this understanding, more research is carried out by looking at different perspectives and directions to obtain the required performance of the structures under seismic loading. [2], [23], [24], [16]. Chimneys are one of the main parts of an industrial plant. If a malfunction occurs in the chimney, this creates a significant economic loss. Generally, concrete chimneys are among the longest, most sophisticated man-made structures in the world and they are often exposed to some of nature's strongest forces. Impact occurring in structures effecting under dynamic loads and vibrations causes many damages in structures that are caused by vibration that do not require intervention. In this case, the vibration must be known and can occur in nature and will focus on the effects of these vibrations. Local geological soil conditions change the properties of the surface seismic response.

In recent years, the definition of systems and health monitoring of buildings has gone from being just an academic research area to an accepted condition assessment method. While performance-based concepts have a good analytical and experimental basis, the actual behavior of structures may differ from what was predicted due to many uncertainties. The processes used in various engineering fields for an unknown system based on a series of input outputs are examined within the scope of system identification [5]. System identification (SI) is the creation of a mathematical model of a system model based on inputs and outputs. System identification method is used in many engineering fields today. Many academic studies are carried out on the system definition method with each passing day in order to obtain more reliable and clearer results. System identification method in civil engineering is used for building systems. By creating a mathematical model of the building, possible earthquake inputs are given and the behavior of the building is determined. Based on these findings, the building system is strengthened. In addition, with the system identification, the current state of the building system and the characteristic features of the building system can be determined. This method is successful in the creation of the mathematical model of systems excited under ambient vibration, and in the light of the studies proving this. It is known that the accuracy of the mathematical model has a direct role in predicting the responses of a building system exposed to various inputs (Earthquake etc.). Therefore, it was decided to use the Subspace system identification method in this study.

Subspace system identification is introduced as a powerful black-box system identification tool for structures. Particular emphasis has been put on the implementation of methods of supporting excited structures. On the use of system definition and finite element model (FEM) update techniques, Tuhta et al [3], [7], [17], [18], [31] was used to define the modal properties of some studies for ambient vibrations in their studies. Several experimental studies have been conducted on concrete chimneys for the measurement of natural frequencies and damping rates to be used in response estimates.

Brownjohn et al. (2010) examined the system identification and the finite element model (FEM) update of the reinforced concrete chimney.

In subspace systems where the character state space models are defined, the modal properties of the structures (ie, modal damping, frequency and mode shapes) can be estimated. [8]. In classical approaches (right), a high grade model is defined and then a model reduction technique is applied to obtain a low grade model. [10]. In this article, many free structural system problems that do not contain a limited number of elements are investigated. As is known for similar types of systems, system matrices [m], [c], [k] can only be created by FEM, and for a finite dimensional linear-dynamic system, the motion equation is a series of n2 second-order differential equations arranged as. [1]. (Equation 1a)

$$[m]\{\ddot{u}(t)\} + [c]\{\dot{u}(t)\} + [k]\{u(t)\} = [d]\{f_{\oplus}(t)\}$$

(Eq. 1a)

Here, the direct stiffness method is used for application in the finite element method and the building system mass, damping and stiffness matrices ([m]; [c]; [k] are used as appropriate.

For example, The FEM implementing system stiffness matrix [k] is shown as follows by the direct stiffness method

$$[\bar{k}_r] -> [\bar{\bar{k}}_r] = [C_r][\bar{k}_r][C_r]^T -> [\bar{\bar{k}}_{r+}] = [\tau_r]^T[\bar{\bar{k}}_r][\tau_r] -> [k.] = \sum_{r=1}^{r.}[\bar{\bar{k}}_{r+}] -> a.b.c. -> [k] \quad \text{(Eq. 1b)}$$

where, $[\bar{k}r]$ is the element stiffness matrix in local coordinate system (c.s.) for r-th finite element, $[\bar{\bar{k}}r]$ is the element stiffness matrix in global coordinate system for r-th finite element,

[Cr] is the coordinate transformation matrix from local to global c.s. for r-th finite element,

$[\tau_r]$ is the topology matrix for r-th finite element, a.b.c. is abbreviation "mean after application of boundary conditions", r_* is a number of identical finite elements examined system,

[k] is the stiffness matrix of the in examined system in global c.s. The main relationships of the FEM are based on the Lagrange principle of variation.

The equation of motion (1) are transformed to the state-space former of first order equations- i.e., a continuous-time state-space model of the system is evaluated as

$$\{\dot{z}(t)\} = [A_c]\{z(t)\} + [B_c]\{f_\oplus (t)\} \quad \text{(Eq. 2a)}$$

$$[A_c] = \begin{bmatrix} [0] & [I] \\ -[m]^{-1}[k] & -[m]^{-1}[c] \end{bmatrix} \quad \text{(Eq. 2b)} \qquad [B_c] = \begin{bmatrix} [0] \\ [m]^{-1}[d] \end{bmatrix} \quad \text{(Eq. 2c)}$$

$$\{z(t)\} = \begin{bmatrix} u(t) \\ \dot{u}(t) \end{bmatrix} \quad \text{(Eq. 2d)}$$

As the response of the dynamic system is measured by the m_1 output quantities in the output vector {y(t)} using sensors (such as accelerometers, velocity, displacements, etc.,), for system model represented by the equations (2), appropriate measurement-output equation become as

$$\{y(t)\} = [C_a]\{\ddot{u}\} + [C_v]\{\dot{u}\} + [C_d]\{u\} = [C]\{z(t)\} + [D]\{f_\oplus (t)\} \quad \text{(Eq.3a)}$$

$$[C] = [\,[C_d] - [C_a][m]^{-1}[k], \quad [C_v] - [C_a][m]^{-1}[c]\,] \quad \text{(Eq.3b)}$$

$$[D] = [C_a][m]^{-1}[d] \quad \text{(Eq. 3c)}$$

As {u} is the displacement vector; [Ac], is an n_1 ($n1 = 2n_2$; n_2 is the number of independed coordinates) by n_1 state matrix ; [d] is an n_2 by r_1 input infuence matrix, characterizing the locations and type of known inputs $\{f_\oplus(t)\}$; [Ca] ; [Cv] ; [Cd] are output influence matrices for acceleration, velocity, displacement for using sensors (such as accelerometers, tachometers, strain gages, etc.,) respectively; [C] is an $m_1 \times n_1$ output influence matrix for the state vector {z} and displacement only; [D] is an $m_1 \times r_1$ direct transmission matrix; r_1 is the number of inputs; m_1 is the number of outputs.

In the output - only modal analysis environment, the main assumption is that input force $\{F(t)\} = [d]\{f_\oplus(t)\}$ comes from white noise or time impulse excitation. Under this hypothesis discrete-time stochastic state {space model may be written as:

$$\{z_{k+1}\} = [A]\{z_k\} + [B]\{f_{\oplus k}\} + \{w_k\} \quad \text{(Eq. 4)}$$

$$\{y_k\} = [C]\{z_k\} + [D]\{f_{\oplus k}\} + \{v_k\} \quad \text{(Eq. 5)}$$

where $\{z_k\} = \{z(k\Delta t)\}$ is the discrete-time state vector; is the process noise due to disturbance and modeling imperfections; $\{v_k\}$ is the measurement noise due to sensors' inaccuracies; $\{w_k\}, \{v_k\}$ vectors are nonmeasurable, but assumed that they are white noise with zero mean.

If this white noise assumption is violated, that is, if the input contains some dominant frequency components in addition to white noise, these frequency components cannot be separated from the eigenvalues of the system and appear as eigenvalues of the system matrix [A]. In real structures emitted from ambient vibration, the input $\{f_{\oplus}(t)\}, \{f_{\oplus k}\}$ remain unmeasured and therefore, disappear from equations in order of (2) - (5). To take into account this fact later, the input is implicitly modeled implicitly with noise terms$\{\underline{w}_k\}\{\underline{v}_k\}$, that do not contain an input that can be measured from ambient vibration, and the said relationship is as follows:

$$\{z_{k+1}\} = [A]\{z_k\} + \{\underline{w}_k\}$$
(Eq. 6)

$$\{y_k\} = [C]\{z_k\} + \{\underline{v}_k\}$$
(Eq. 7)

DESCRIPTION OF MODEL CONCRETE CHIMNEY:

In this paper, Model concrete chimney is 0.48 m in height. Thickness of elements is 0.01 m. Model concrete chimney has a flat cylinder shape. The diameter of the chimney is 0.12 m. Model concrete chimney is produced from C25 (TS500) ready-mixed concrete. Figure 1 shows the condition of the model concrete chimney on the shaking table. Figure 2 shows the dimensions of the model concrete chimney.

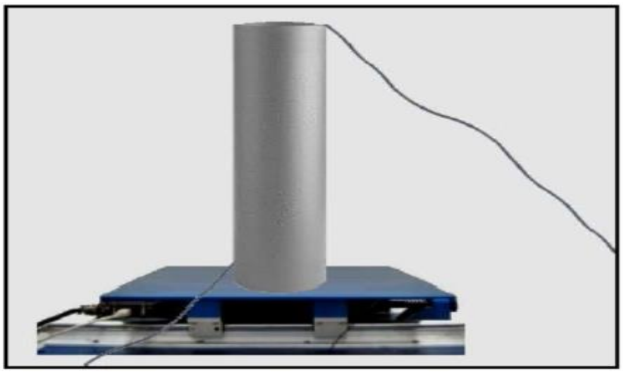


Figure 1: Model Concrete Chimney on Shake Table

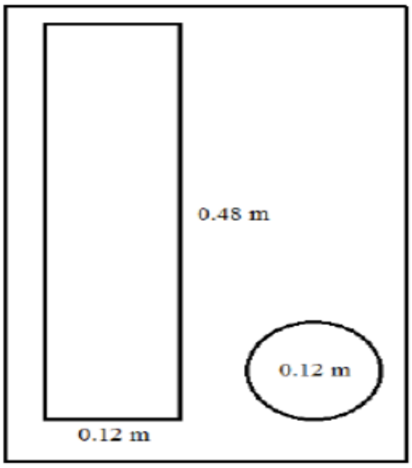


Figure 2: Dimensions of Model Concrete Chimney

NUMERICAL ALGORITHMS FOR SYSTEM IDENTIFICATION DATA AND RESULT:

N4SID methods aim to approach the state order of the system and use this approximate state in a second step to estimate system matrices. It is a method that predicts the state sequence up to N4SID type similarity conversion. The definition of the subspace method is followed by a discussion on the development of subspace identification techniques for nonlinear systems.

The N4SID subspace definition method is based on the fact that it is possible to get the state sequence up to the similarity transformation by saving the input and output data in structured matrices. Data arrays are stored in data matrices with block Hankel structure. The System İdentification Toolbox ™ offers MATLAB® operations, Simulink® blocks and applications to create mathematical models of dynamic systems from measured input-output data. It allows you to create and use dynamic system models that are not easily modelled from the first principles or specifications. You can use time-domain and frequency-domain input-output data to define time - definition and frequency - definition transfer functions, process models, and state-space models. The toolbox also provides algorithms for embedded online parameter estimation [9].

sys = n4sid(data,nx) estimates a discrete-time state-space model sys of order nx using data, which can be time-domain or frequency-domain data. sys is a model of the following form:

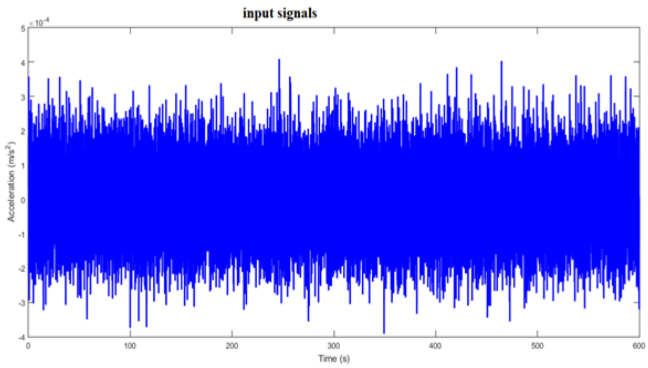
A, B, C, D, and K are state-space matrices. u(t) is the input, y(t) is the output, e(t) is the disturbance, and x(t) is the vector of nx states.

All entries of A, B, C, and K are free estimable parameters by default. For dynamic systems, D is fixed to zero by default, meaning that the system has no feedthrough. For static systems (nx = 0), D is an estimable parameter by default.[9].

The data obtained from the sensors were processed with the System identification toolbox of MATLAB software. The data obtained by MATLAB software are presented as images one by one. The pictures obtained with the description of the model concrete chimney subspace system are given in figure 3 - 10.

They were examined respectively;

- İnput and Output Signals
- Model Output - Fit to estimation data
- Power Spectrum Graphics
- A, B, C, D and K matrices
- Autocorrelation of Residuals for Output
- Frequency Function
- Poles and Zeros
- Noise Spectrum
- Periodogram Graphics



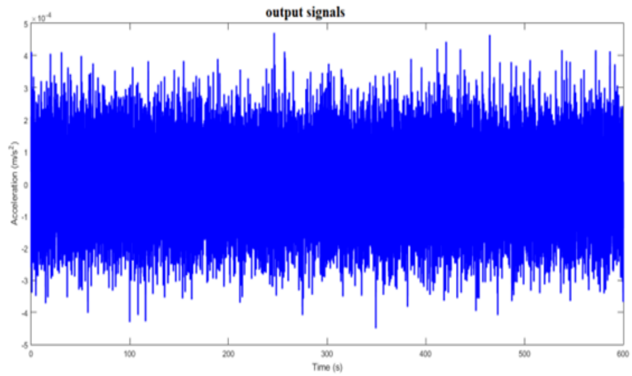


Figure 3: Input and Output Signals

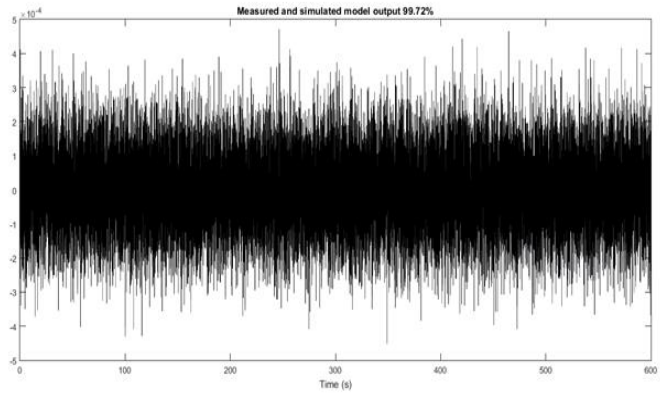


Figure 4: Model Output – Fit to Estimation 99,72%

The model output ratio is approximately between 0.0004 and -0.0004 is shown in Figure 4.

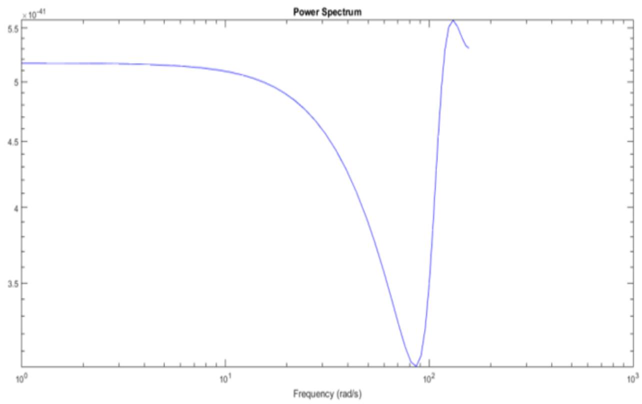


Figure 5: Power Spectrum Graphics

A, B, C, D and K Matrices of Model Concrete Chimney;

Discrete-time identified state-space model:

x(t+Ts) = A x(t) + B u(t) + K e(t)

y(t) = C x(t) + D u(t) + e(t)

$$A=\begin{bmatrix} -0.3604 & -0.6108 & 0.4993 & -0.2631 \\ 0.3184 & -0.5847 & 0.4518 & -0.1691 \\ 0.0507 & -0.8722 & 0.1973 & -0.4141 \\ -0.3129 & -0.4762 & -0.3963 & -0.1597 \end{bmatrix} *1.0e\text{-}14$$

$$B=\begin{bmatrix} -0.2687 \\ -0.0766 \\ -0.0433 \\ -0.2470 \end{bmatrix} *1.0e\text{-}16$$

$$C=[-0.0651 \quad 0.0448 \quad 0.0039 \quad -0.1037]*1.0e\text{-}16$$

$$D=1.1500*1.0e\text{-}16$$

$$K=\begin{bmatrix} 1.9734 \\ 0.2217 \\ 0.1912 \\ -0.8512 \end{bmatrix} *1.0e\text{-}16$$

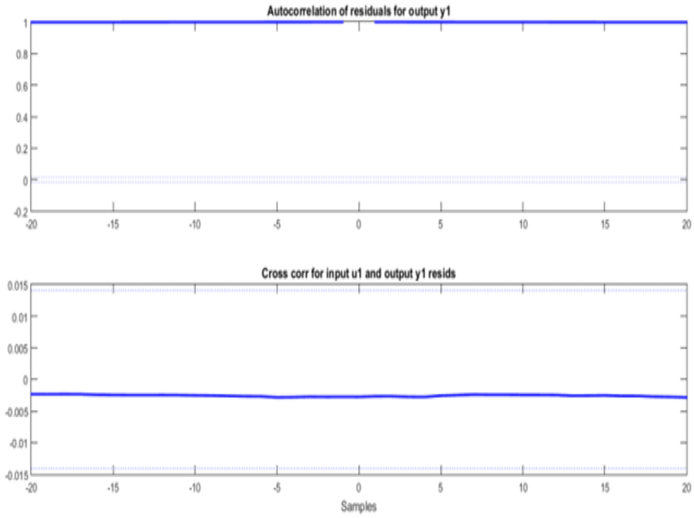


Figure 6: Autocorrelation of Residuals for Output Graphics

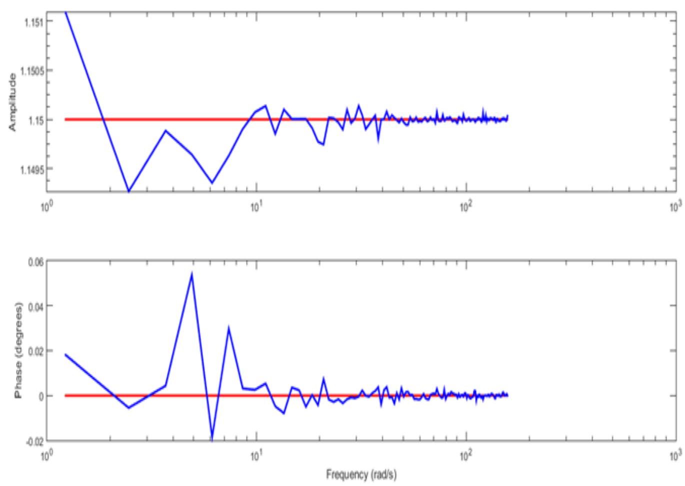


Figure 7: Frequency Function Graphics

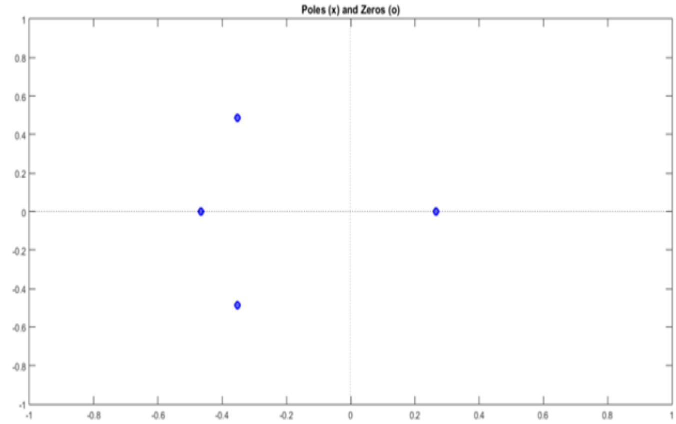


Figure 8: Poles and Zeros Graphics

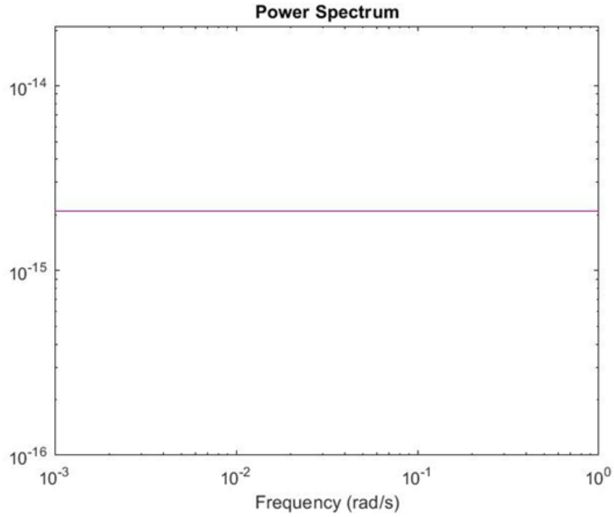


Figure 9: Noise Spectrum Graphics

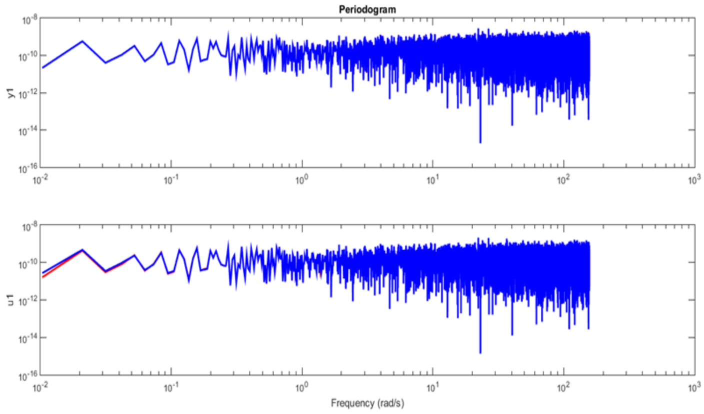


Figure 10: Periodogram Graphics

CONCLUSIONS:

In this article, the theoretical principles of the definition of the subspace system applied to the problem of predicting black box state space models of excited structures (eg structures exposed to earthquakes) are reviewed.

This study differs from past studies by providing readers with a strong geometric interpretation of subspace operations that are directly related to theoretical structural dynamics. To validate the performance of subspace system identification, a series of experiments were conducted on Model Concrete Chimney exposed to moderate seismic ground motions; structural response data is used off-line to estimate mathematical models. Ground motion and structural response measurements have been used to derive a complete input-output state-space model of the Model Concrete Chimney by the sub-model system identification method. The modal parameters of the structure are extracted from the estimated input–output state-space model. By using only structural response data, only the output state-space models of the system can be estimated by the subspace system definition.Finally, System identification of Model Concrete Chimney was successfully realized and system matrices were put forward. Thus, mathematical model was created at % 99.72. Also;

- A, B, C, D and K matrices of the system were obtained.
- Input and output signals were obtained.
- Transient Response another meaning step response values were obtained.
- Frequency Function was obtained and values were calculated.
- Poles and Zeros were obtained.
- Noise Spectrum was obtained.
- Model Residual Analysiswere conducted.

It can be concluded that the N4SID system identification method is effective and accurate in determining the modal data of a Model Concrete Chimney test.

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