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Effect of Input Baseline Correction on Sliding and Tipping

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ABSTRACT

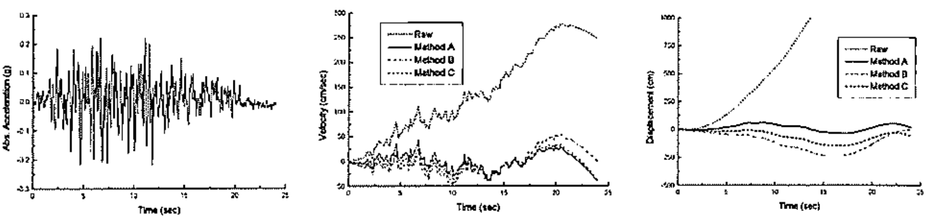
When sliding or tipping analysis is performed for a nonlinear structure, horizontally bidirectional analysis is highly recommended. It is because the nonlinear response can be very sensitive to the baseline correction of earthquake input and because single horizontal component analysis may mislead the design to an excessively conservative one or vice versa. This is likely to happen in analyses using old computer programs, which are limited to one dimensional modeling and solving. In this paper, it is investigated how the baseline correction of earthquake input affects to the nonlinear responses by one horizontal component exitation and by two. On this purpose, example analyses for a rigid block or a free standing system are performed. As a result, set-up of a standard method or guideline for baseline correction of seismic input is thought to be necessary for nonlinear system design.

1. INTRODUCTION

In seismic design of free standing structures, sliding and tipping are normally considered as the most important nonlinear behaviours. In sliding and tipping analyses, the peak response is one of the major concerns. It is because such equipment are normally designed to keep enough margin of space based on the analysis result[1]. To assure no impact between structures and to prevent overturning of structures during earthquake, reliable prediction of response is required. To solve the equations of motion of a mathematical model of such a nonlinear structure on a computer, accelerograms are used as input exitation. Design earthquake given in time history form, whether it is recorded or artificially generated, is baseline corrected in general. If not, however, baseline correction should be performed prior to use for sure to avoid potential unconservative design. All the equipment designers have to do in linear seismic analysis is known to apply the accelerogram as an input without any special care, in most cases. In nonlinear seismic analysis of the structures expected to slide or tip during earthquake, however, the analysis method and result should be basically checked in viewpoint of reasonablity and conservatism. In following chapters, it is discussed why especially the unidirectional nonlinear analysis should be performed with great care.

2. METHODS OF BASELINE CORRECTION

Baseline correction has been performed to compensate the baseline translation of the accelerograms caused by instrument error or by digitizing error. To much extents in general, those errors can be reduced through operator training and calibration by test signal and etcs. Without enough information about the cause of errors, anyway, correction should be made because the integration process is critical for long period motions like the design earthquake for nuclear power plant. Only by looking at the accelrogram records, specific trend or errors can hardly be found. If the zero baseline of the accelerogram is translated by a small amount, it is equivalent to adding a step function error to the accelerogram. By integrations, this error firstly yield a linearly increasing velocity curve, and secondly yield a parabolically increasing displacement curve. This type of error or unwanted trend insertion can be removed by baseline correction This can be easily seen in Fig.1.



a) Acceleration b) Velocity c) Displacement

Fig.1 Change of Input Earthquake by Baseline Correction
(sampled from UCN 3&4)

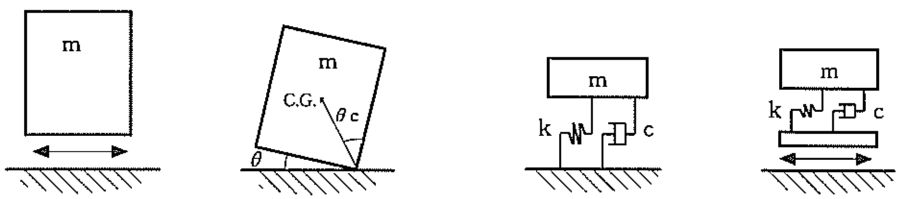
Unfortunately, however, there seem to be no fixed rules or guidelines found for the method of baseline correction by regulatory authorities yet. Therefore, the vendors in charge of nonlinear analysis seem to make and use their own methods of baseline correction when necessary. Followings are a couple of representative methods known to be used by engineering vendors.

Method A : This is used in comercial analysis program ABAQUS[2], which is based on the method proposed by proffesor Newmark. The raw data is subtracted by a parabolic calibration function which satisfies the condition of minimization of average square sum of integrated velocity history.

Method B : This is used by vendors, The raw data is subtracted by a linear calibration function which satisfies the condition of zero velocity and zero displacement at the end of earthquake.

Method C : This has been also used by vendors. It uses a constant value as calibration function which satisfies the condition of minimization of average square sum of integrated velocity history.

In this paper, the method A and B are typically applied to investigate the variation of effect on the result of analysis.



a) Sliding Block b) Tipping Block c) Fixed System d) Sliding System

Fig.2 Models for Sliding and Tipping Analysis

3. DESCRIPTION OF ANALYSIS

3.1 Equations of Motion

To investigate the effect of baseline correction on nonlinear system, Four different types of model were set up. They are a rigid sliding block, a rigid tipping block, a lumped mass spring-damper system with sliding base, a lumped mass spring-damper system with fixed base as shown in Fig.2. The governing equation of motion for sliding system in Fig.2d can be expressed as follows[4],

$$m\ddot{x}_1 - c\dot{x}_2 - kx_2 + f_x = -m\ddot{x}_g \qquad (1a)$$

$$m\ddot{y}_1 - c\dot{y}_2 - ky_2 + f_y = -m\ddot{y}_g \qquad (1b)$$

$$m\ddot{x}_2 + c\dot{x}_2 + kx_2 = -m(\ddot{x}_g + \ddot{x}_1) \qquad (1c)$$

$$m\ddot{y}_2 + c\dot{y}_2 + ky_2 = -m(\ddot{y}_g + \ddot{y}_1) \qquad (1d)$$

where, m, c, k are mass, stiffness, damping of the system whose dynamic characteristics in two orthogonal horizontal directions are assumed to be the same on analysis purpose. f_x , f_y are friction forces in x, y direction at the system base, respectively. x_g, x_1, x_2 and y_g, y_1, y_2 are the earthquake ground motion, displacement of system base relative to ground, displacement of system superstructure relative to its base in x and y direction, respectively. Therefore, equation (1) becomes the equation of motion for the linear system shown in Fig.2c by making x_1 and y_1 equal to zero, and becomes the equation of motion for the rigid block shown in Fig.2a by putting x_1, y_1, c, k equal to zero. For unidirectional sliding analysis, equation (1a)&(1c) and (1b)&(1d) sets are treated seperately at first. Then, the whole equation (1) are treated together to consider the bidirectional effect[3]. For the tipping analysis, a rigid block is assumed free to rock without sliding on either of its base corners as shown in Fig.2b. The governing equation of motion for the tipping block can be expressed as follows,

$$I\ddot{\theta} + mr\ddot{x}_g \cos(\theta_c - \theta) + mgr\sin(\theta_c - \theta) = 0, \qquad \theta \geq 0 \qquad (2a)$$

$$I\ddot{\theta} + mr\ddot{x}_g \cos(\theta_c + \theta) - mgr\sin(\theta_c + \theta) = 0, \qquad \theta \leq 0 \qquad (2b)$$

where, I are the moment of inertia of the block about base corner, m , the block mass, r the distance from center of gravity to base corner, tipping angle of the block with respect to the ground, θ_c critical angle between the center of gravity the block edge with respect to the base corner. The moment of inertia I and the coefficient of restitution e are assumed to satisfy following relations.

$$I = \tfrac{4}{3}mr^2 \qquad (3a)$$

$$e = 1 - \tfrac{3}{2}\sin^2\theta_c \qquad (3b)$$

And, $\ddot{x}_g$, g are the earthquake ground acceleration and the gravitational acceleration, respectively.

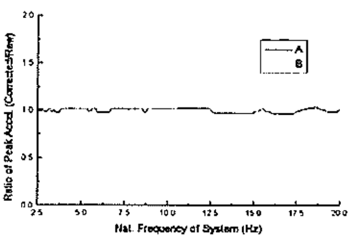
3.2 Numerical Analysis

Numerical analyses are performed for the mathematical models described above using the raw data of seismic inputs and baseline corrected ones. Two of unidirectional analyses and a bidirectional analysis were done as a set for each sliding model to study their sensitivity in displacement response with respect to input baseline correction methods. Typical parameters used in the analysis are ; 0.04 for the damping ratio of the system, 0.01 for the friction coefficient commonly for the block and sliding system. The raw data of earthquake input is sampled from ones used for the equipment design of Ulchin Nuclear Unit 3&4. The sixth order Runge-Kutta scheme and double precision were chosen for numerical integration of the equations of motion in FORTRAN. A time step of 0.0005 second was used for the numerical integration when sliding and non-sliding phases were involved due to the friction mechanism[1]. The response time histories during the first 24 seconds were used to calculate the peak responses of the system. The units of the displacement and acceleration are respectively cm and g.

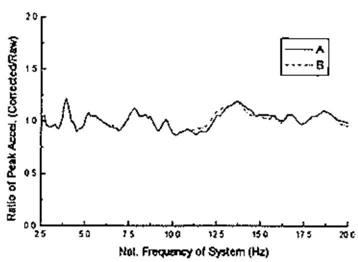
4. RESULT AND DISCUSSION

4.1 Linear System and Nonlinear System

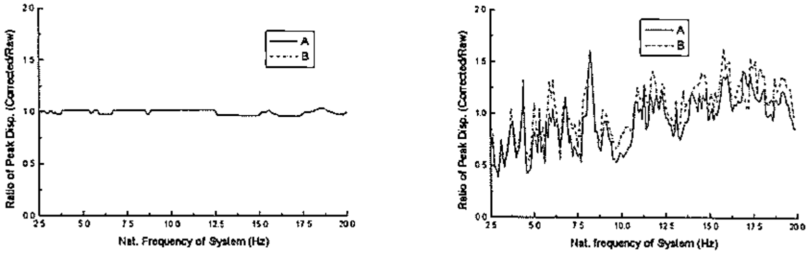
To compare the effect of input baseline correction on the peak responses of linear system and nonlinear system, systems with fixed base and sliding base are chosen as the representatives for each. And, peak acceleration and displacement are investigated by varying their natural frequencies. As shown in Fig. 3a and 3c, the linear systems are hardly affected by baseline correction both for acceleration and displacement. That is, the ratio of peak responses by corrected input devided by the ones by raw input sticks to unit with variation of less than 5% regardless of the system natural frequencies.



a) Acceleration of Linear System



b) Acceleration of Nonlinear System



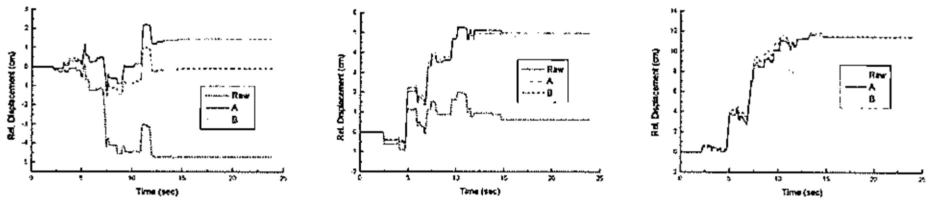
c) Displacement of Linear System   d) Displacement of Nonlinear System

Fig.3 Comparison of Correction Effect on Linear and Nonlinear System

On the contrary, the responses of sliding system as shown in Fig.3b and 3d seems to be somewhat sensitive to input baseline correction, especially for the peak displacement.

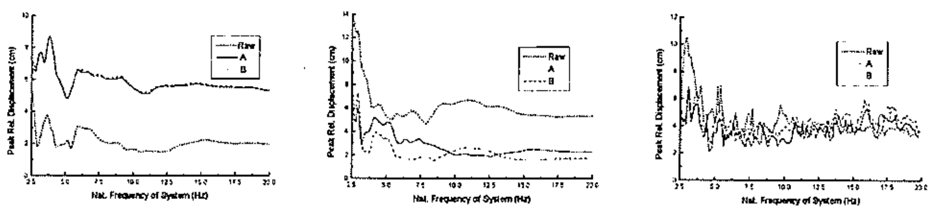
4.2 Sliding Block

In Fig.4, the relative displacements versus time are plotted for a sliding rigid block, using inputs in a) EW direction, b) NS direction, c) both directions. An interesting fact is found from Fig.4. The response result using raw input data is greater than those using the corrected input in EW directional analysis(Fig.4a).



a) EW direction   b) NS direction   c) bi-direction

Fig.4 Sliding displacement history from unidirectional vs. bidirectional analyses



a) EW direction   b) NS direction   c) bi-direction

Fig.5 Peak sliding responses from unidirectional vs. bidirectional analyses

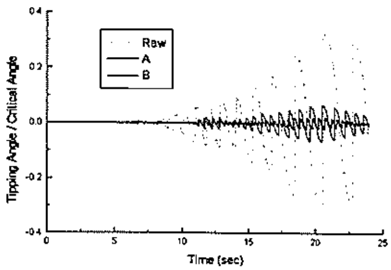
But, this trend turns out in reverse way in NS directional analysis(Fig.4b). Therefore, a shade difference is seen from the result of sliding analysis considering bidirectional effect(Fig.4c). This seems to be based upon the offset effect of two opposite trend.

4.3 Sliding System

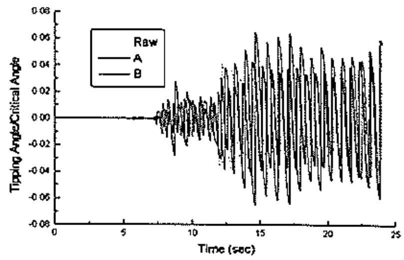
Fig.5 shows peak relative displacements versus natural frequencies of 2.5Hz to 20Hz of sliding system for unidirectional and bidirectional analyses. Fig.5a is plotted for EW dirction sliding analysis using three different input exitation. In all frequency range, the response by corrected input significantly exceeds the response by raw input. On the contrary, the response by raw input largely exceeds the response by corrected input in NS dirction sliding analysis as shown in Fig.5b. This means the unidirectional sliding analysis can potentially yield excessively conservative result or rather a much less conservative result. In addition, there exist a level of difference even between the baseline correction methods more than twice in some frequency range. In sliding analysis considering bidirectional effect as in Fig.5c, the peak responses by three different inputs are roughly within some allowable limit by the offset of two opposite trend, while there still remains some frequency ranges of ratio of about two.

4.4 Tipping Block

Fig.6 shows comparison of tipping angle history of rigid block by unidirectional analysis using EW or NS directional input. The vertical axis represents the ratio of tipping angle to critical angle. In this analysis, a value of 400cm as width and a value of 5 as the ratio of height to width are applied to both of horizontal two directions for reference. From the result of EW direction analysis, it can be concluded that the tipping angle is quite sensitive to the baseline correction of seismic input. Analysis result using the corrected input by method-A yields the least tipping. With the raw data, it may easily lead to a result of overturning for a slightly increased slenderness case while the result using corrected data has still enough margin as shown in Fig.6a. By the way, the trend of result analysed using the NS input in orthogonal direction is somewhat different from that of sliding casesas shown in Fig.6b It depicts the resultant tipping angle by NS direction analysis remains much less than EW one about by one order of difference. In tipping analysis, it seems hard to predict the result of bidirectional analysis and to judge like sliding cases above because of the lack of solution considering bidirectional effect at present.



a) EW direction



b) NS direction

Fig.6 Tipping responses for EW and NS unidirectional analyses

5. CONCLUSIONS

A study of these results leads to the following conclusions.

1. Results of peak displacement from unidirectional nonlinear analysis is very sensitive to whether the input earthquake has been baseline corrected or not. So the unidirectional analysis may yields excessively conservative or nonconservative result.
2. Horizontally bidirectional analysis is strongly recommended for the system of nonlinear behaviour like sliding or tipping during earthquake.
3. The variation of result by the difference of baseline correction methods being used in vendors is not in a level of concern as far as bidirectional analysis is performed.

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