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Dynamic Characteristics of Spacer Grid Impact Loads for SSE

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안전정지지진에 대한 Spacer Grid 충격하중의 동특성

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Abstract

This paper investigates the dynamic characteristics of spacer grid impact loads and the effects of variations in the amplitude and frequency of the core plate motions on the resultant impact loads. A model of the longest row (15 fuel assemblies) across the core is analyzed using the input motions generated from safe shutdown earthquake. Input excitations consist of time history motions applied to the core support plate, fuel alignment plate and core shroud. The responses are determined for a set of four parameter runs with respect to the amplitude and frequency changes. Spacer grid impact loads and normalized input values for all cases are presented. The results show that changing the natural frequency has negligible effect but changing the amplitude of the input motions has a significant effect on the grid impact loads. Therefore, time history analysis is not necessary for a shifted case to get the core responses under the seismic excitation.

요 약

본 논문은 안전정지지진에 대한 spacer grid 충격하중의 동적특성을 고찰한 것이다. 안전정지지진 (SSE : Safe Shutodown Earthquake)을 가진력으로 사용하였고 모델로는 가장 긴 15 row의 핵연료집합체 모델을 사용하였다. 외부에서 제공되는 입력데이타의 불확실성을 보상하기 위하여 흔히 사용되는 10% 증가된 입력값과, NRC 권고사항인 입력응답 스펙트럼의 이동효과의 영향이 평가되었다. 평가대상으로는 spacer grid의 충격력이 사용되었다. 해석결과로서 입력응답 스펙트럼의 이동효과의 영향은 거의 무시할 수 있으나 증가된 입력값의 영향은 spacer grid의 충격력에 큰 영향을 줌을 알 수 있었다. 따라서 원자로노심의 동적응답을 위해서는 입력응답 스펙트럼을 이동시키면서 해석할 필요가 없음을 확인하였다.

1. Introduction

For the dynamic response evaluation of reactor internals under pipe break or seismic excitations, the coupled internals and core model is used by lumping all fuel assemblies into several groups.

The fuel assembly responses obtained from this analysis are not accurate because reduced fuel assembly model is used. Therefore, the detailed core analysis is necessary to determine the spacer grid impact loads and peak displacement shapes of fuel assemblies during postulated pipe breaks or earthquake.

Regulatory Guide 1.122 (Ref. 1) describes the methods for developing design response spectra at various floors from the time history base motions. To account for the uncertainties in the structural frequencies owing to uncertainties in the material properties and approximations of the modeling techniques, the floor response spectra should be smoothed and the peaks associated with each of the structural frequencies should be broadened by 10 %. In addition, it is an engineering practice to increase the amplitude of the input motions by 10 % to account for the uncertainties of the input motions supplied by external group.

In this paper the effect of two parameters, shifted frequency and increased input amplitude, on the spacer grid impact loads for seismic excitation is investigated. Also the dynamic characteristics of the spacer grid impact history are discussed.

2. Model Development

In the detailed core model, the fuel assemblies are modeled as uniform beams. Lumped masses are included at spacer grid locations to represent the significant modes of vibration of the fuel and to account for the possible spacer grid impacting. The gap–spring elements are used to simulate the geometric non–linearities between the fuel assmblies as well as the clearance between the peripheral fuel assemblies and core shroud. The nominal gap sizes of 0.148 and 0.075 inch are used for core shroud peripheral and fuel assembly gap, respectively. Each spacer grid is characterized by the dual load path model which has two independent stiffness parameters calculated from the one–sided and through–grid stiffnesses of the spacer grid and so represents the load paths associated with both one–sided and through–grid impacts(Fig. 1).

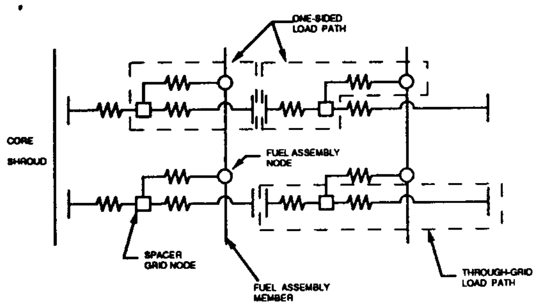

Fig. 1. Dual Load Path Impact Model of Spacer Grid

The fuel analytical model was constructed by calculating nodal properties for corresponding locations based on the weight distribution data. The dynamic characteristics of the fuel bundle including natural frequency and damping were also determined from the test data. The static model of the fuel bundle was modified to include dynamic effects by adjusting the bundle stiffness to obtain the proper natural frequency and prescribing the damping as a percentage of critical damping. Hydrodynamic (diagonal coupling coefficients) mass was added to the structural mass to obtain the proper natural frequency in water. The off–diagonal coupling terms are not considered in the core model, that is, hydraulic coupling between the fuel assemblies is neglected. This was justified by water loop tests (Ref.3), which indicate that the natural frequency drop can be accounted for by added masses corresponding to the displaced liquid, meaning that a fuel assembly in a channel doesn't behave in a significantly different manner as a fuel assembly in an infinite fluid. Physically this means that without a wrapper

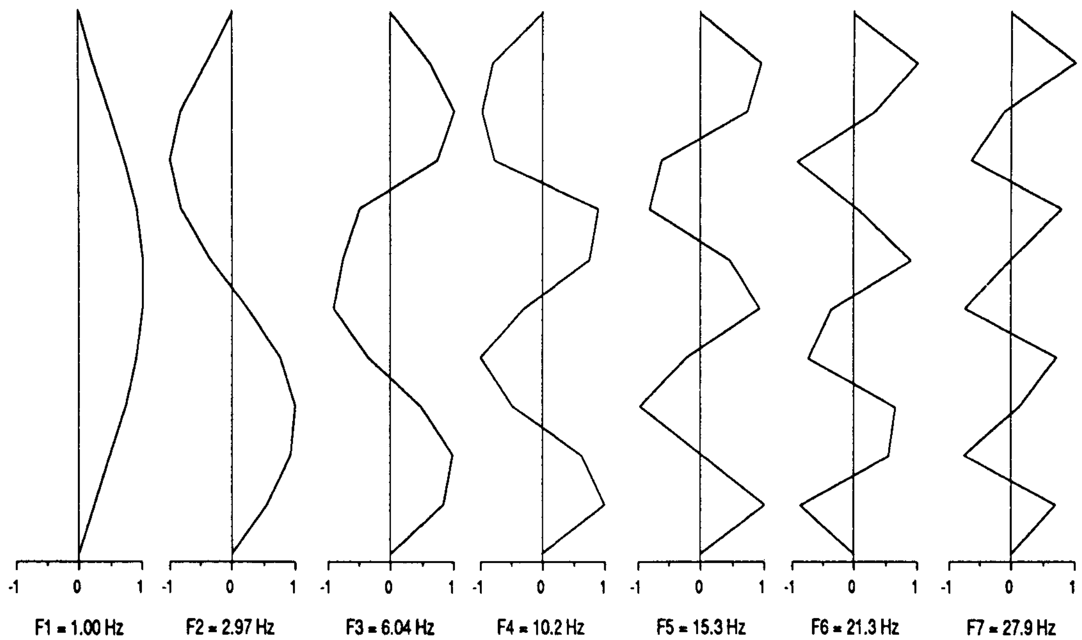

Fig. 2. Mode Shapes of Fuel Assembly

tube, the fluid can flow from one side of the assembly to the other, across the fuel assembly rather than around it. After the dynamic model of the fuel bundle was established, the model of the spacer grid was developed. The spacer grid model separates out through–grid and one–sided load paths. Ref. 2 indicates that fuel assemblies in the longest rows (15 fuel assemblies) experience the severest response for the seismic excitations. Therefore, core model of fifteen fuel assembly rows is used here.

To verify an accurate representation of the fuel assembly, the mode shapes and natural frequencies were obtained and compared with test data(Fig.2).

3. Dynamic Responses

The input excitations to the detailed core model consist of the translational and angular time histories of the core plates and the translational time history of the core shroud. They are determined from the coupled internals and core analysis using the reactor vessel motions of Fig.3 for forcing functions. The fuel alignment plate, core support plate and core shroud motions indicated that the relative horizontal displacement is small in comparison with the translational motion (Figs. 4 and 5). The core plates together with core shroud translate horizontally as a rigid body.

The responses are determined for a set of four parameter runs with respect to the amplitude and frequency changes as shown in Table 1. A fuel assembly model with a first mode natural frequency of 1 Hz is excited for the nominal time history. Three additional input time histories are obtained by scaling the time and/or amplitude values of the base input time history and the responses are compared with those of base case. In Case 2, the frequency of the spectrum is shifted by 10 %. For Case 3, the base frequency is used but the input motions are increased by 10 % resulting in 10 % increase of the acceleration response spectrum. Case 4 has an acceleration response spectrum

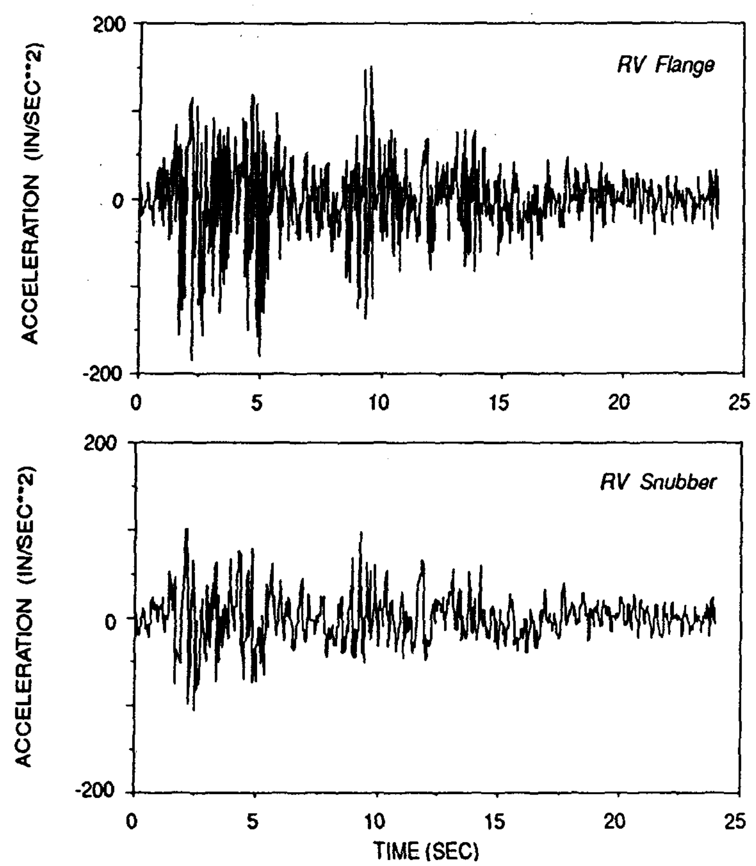

Fig. 3. Acceleration Time Histories of RV Flange and Snubber

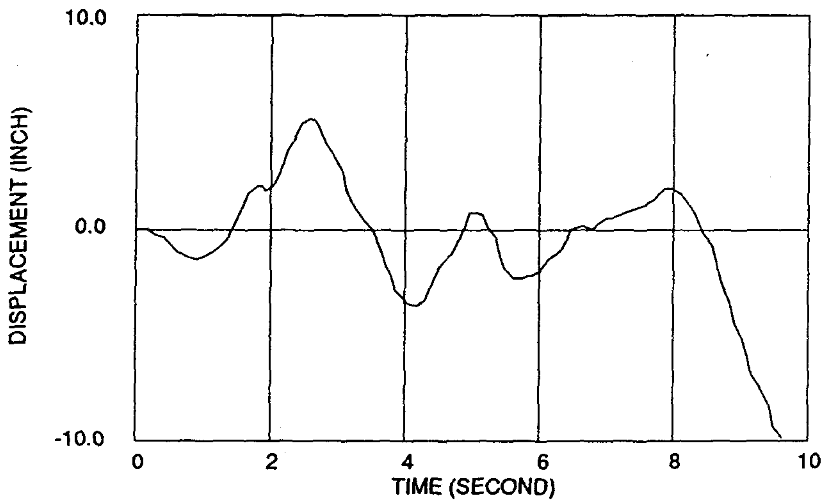

Fig.4. Core Plates and Core Shroud Motions

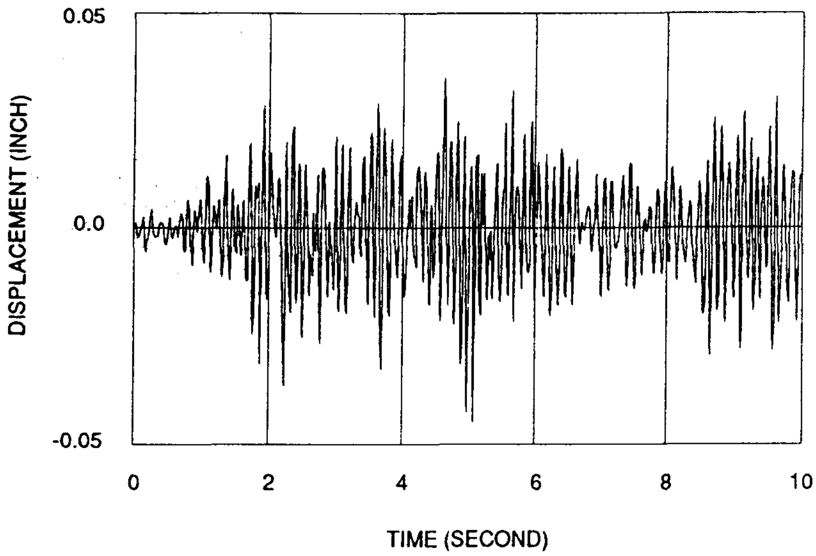

Fig. 5. Relative Displacement of Fuel Alignment Plate to Core Support Plate

Table 1. Input Variables for Each Case (Normalized)

CASE	FREQUENCY		INPUT MOTIONS	
	Δt	PEAK SHIFTED	CORE PLATE MOTION	CORE SHROUD MOTION
1(base)	1.0	1.0	1.0	1.0
2	1.1	.91	1.0	1.0
3	1.0	1.0	1.1	1.1
4	1.1	.91	1.1	1.1

shifted by 10 % and input motions increased by 10 %. The acceleration response spectra of core plates are shown in Fig.6.

The equation of motion for the structural system is described by the second–order differential equation as follows :

$$[M]\{A\} + [C]\{V\} + [K]\{X\} = \{F(t)\}$$

where [M], [K] and [C] are defined as the mass, spring and damping matrices and {A}, {V}, {X} and {F(t)} are defined respectively as the acceleration, velocity, displacement and force vectors. The responses of the fuel assemblies to the excitations were obtained using the SHOCK code (Ref.4), which integrates the equations of motion by the Runge–Kutta–Gill method or a Newmark method for first–order differential equations and provides the time–history response of the fuel assemblies.

The integration timestep was determined based on the impact pulse which is typically estimated to be 10 milliseconds for seismic excitation. The number of steps per pulse will be $10/(2\times10^{-4})=50$ for the constant timestep of 2×10^{-4} second, which is large enough for this kind of analysis. In this case, the maximum frequency range encompassed is $[(20)(2\times10^{-4})]^{-1}=39.8$ Hz because timestep is almost equal to $(1/20)\times$(minimum

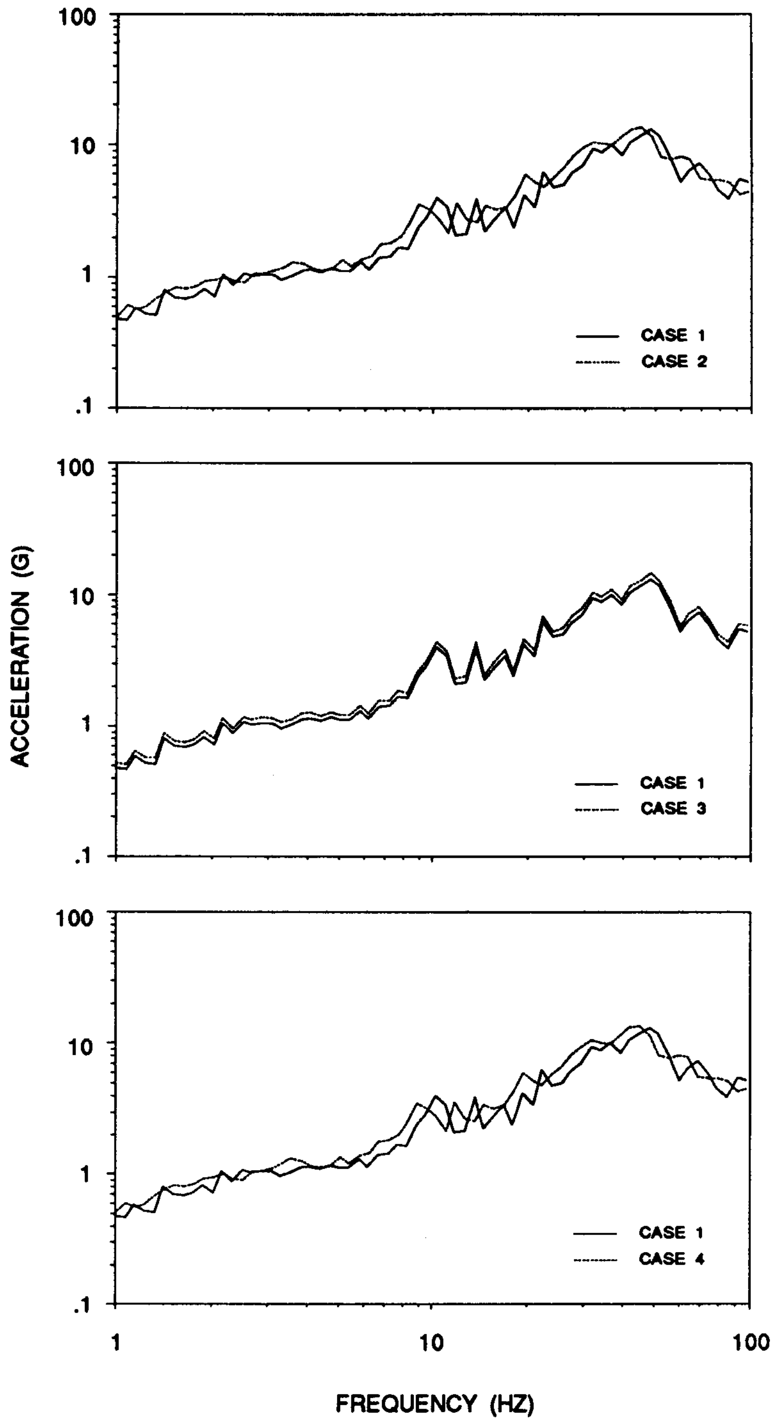

Fig. 6. Response Spectrum of Fuel Alignment Plate

period τ). The 39.8 Hz is wide enough to cover the fuel frequencies because fuel assembly responds to the seismic excitation by moving back and forth approximately at the first mode frequency of 1 Hz(Ref.2).

4. Results and Discussion

The result of the detailed core analysis consists of peak spacer grid impact loads which are used to evaluate the structural integrity of spacer grids. The one–sided and through–grid spacer grid impact loads are summarized in Table 2. One–sided loads are the loads experienced by one side of a grid when it impacts the adjacent grid or the core shroud. Through–grid loads are developed through a grid when it is supported by another grid or the core shroud.

The normalized input values and spacer grid impact loads for all cases are presented in Table 3. The response of shifted cases (Case 2 and 4) shows responses with less than 3 % difference from the corresponding nominal cases (Case 1 and 3), respectively. On the other hand, the increase of the input amplitude by 10 % results in 11 % increase of the responses, which is an almost linear increase.

Fig. 7 shows the relative time histories of displacement and velocity at center spacer grid nodes across the core for the core shroud. The crossings in Fig. 7 indicate shocks. The core maps of one–sided and through–grid impact loads for Case 1 are shown in Fig. 8. Table 4 gives the impact histories for the base case ; each cell contains the number of occurrence of the impact force between the center spacer grids of the various assemblies in the row. For example, 6 one–sided impacts for the spacer grid (right side) of fuel assembly 15 have a maximum force less than 0.4 F_{max} ; 2 impacts have a maximum force between 0.4 F_{max} and 0.5 F_{max}, etc. For the one–sided forces, the impacts on the left and right side of the grid are independent. The damage (if any) to a grid from an one–sided impact occurs to the first few cells, i.e. a left–sided impact does not affect the right side of the grid. Note that the largest impact forces involve peripheral fuel assemblies and center spacer grids.

Table 2. Summary of Spacer Grid Responses

	Case1	Case2	Case3	Case4
One Sided Impact (lbs)	4179	4311	4637	4734
Through–Grid Imact (lbs)	2493	2521	2630	2702

Table 3. Results of Sensitivity Study (Normalized)

CASE	INPUT MOTIONS		IMPACT LOADS	
	PEAK FREQUENCY	INPUT AMPLITUDE	ONE–SIDED	THROUGH–GRID
1(base)	1.0	1.0	1.00	1.00
2	.91	1.0	1.03	1.01
3	1.0	1.1	1.11	1.05
4	.91	1.1	1.13	1.08

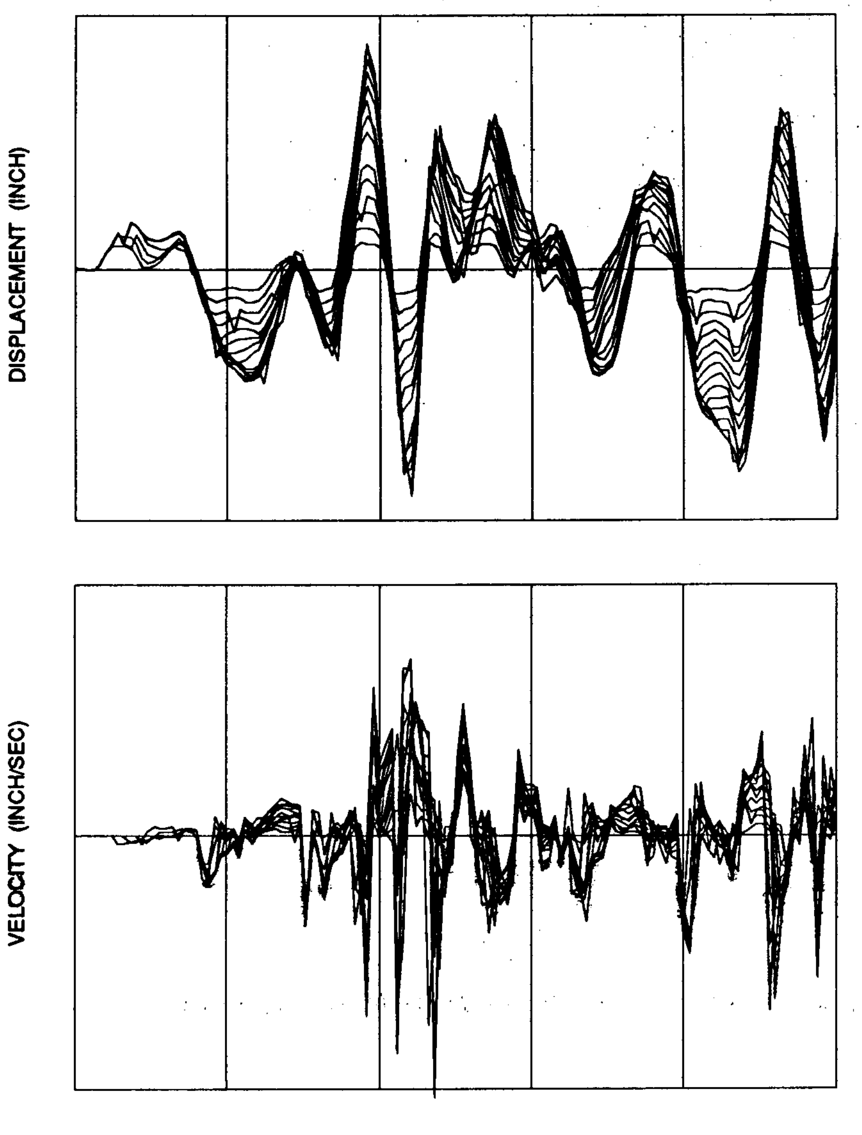

Fig. 7. Relative Displacement and Velocity Time Histories for Center Spacer Grid Nodes

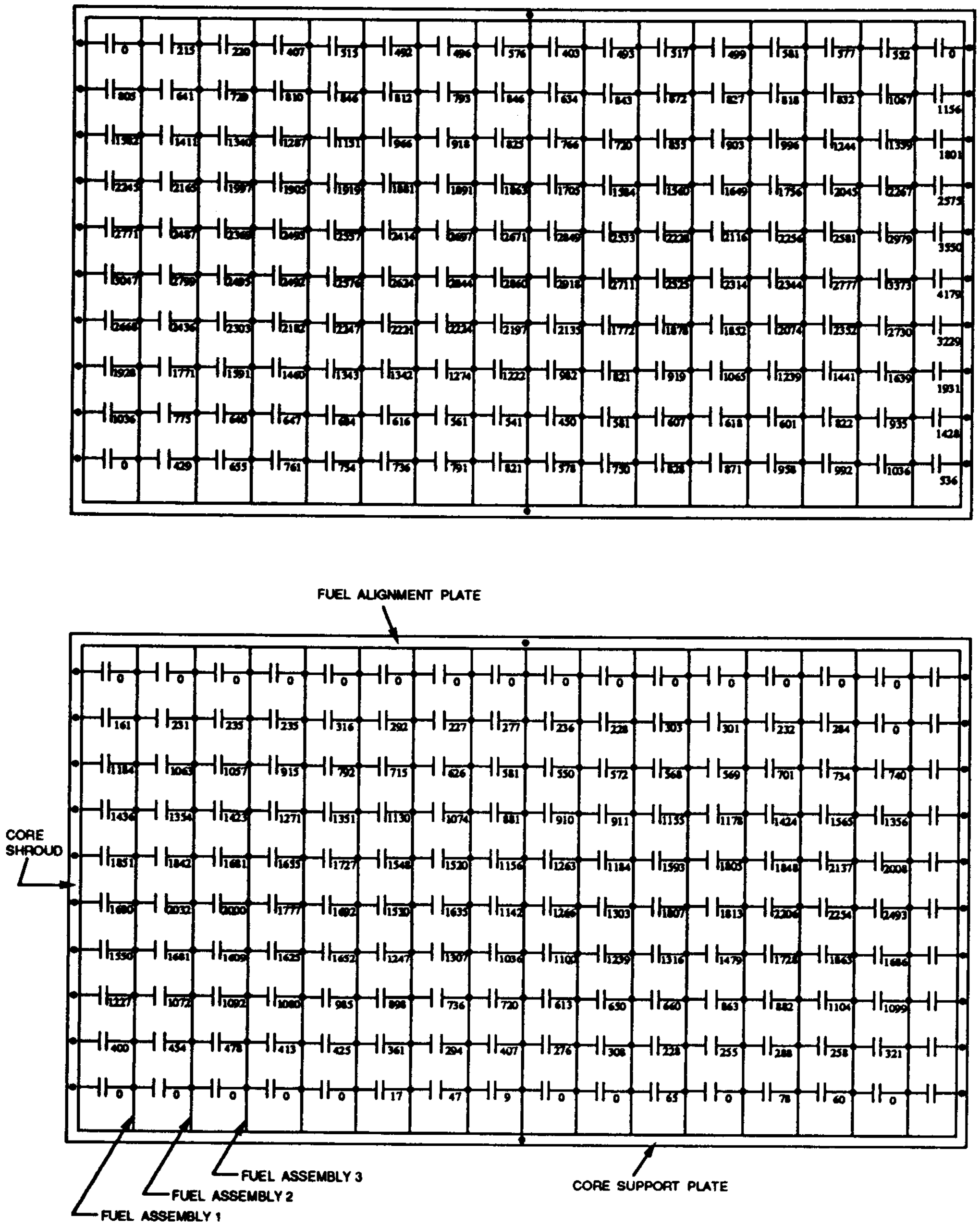

Fig. 8. Core Maps of One Sided (Above) and Through–Grid (Below) Impact Loads

Table 4. Impact Forces at Center Spacer Grid Nodes

	One-Sided IMPACT ($\%F_{max}$)														Through-Grid IMPACT ($\%F_{max}$)						
	Left Side							Right Side													
	40	50	60	70	80	90	100	40	50	60	70	80	90	100	40	50	60	70	80	90	100
FUEL ASSY 1	8	3	0	1				5	1	1					2	1					
FUEL ASSY 2	6	0	1					5							1	1	1				
FUEL ASSY 3	6	0	1					6							1	1					
FUEL ASSY 4	9	0	1					4	2						1	1					
FUEL ASSY 5	2	3	1					6	2						1	1					
FUEL ASSY 6	4	3	1					5	3	1					2						
FUEL ASSY 7	6	4	0	1				4	3	2					5						
FUEL ASSY 8	7	3	2	1				4	3	1	1				4						
FUEL ASSY 9	3	4	3	1				6	2	3	1				3						
FUEL ASSY10	7	2	4	1				7	4	2	1				3						
FUEL ASSY11	7	4	0	1				9	2	2					4	1					
FUEL ASSY12	7	1	2					5	2	2					3	2					
FUEL ASSY13	6	1	2					5	4						1	2	1				
FUEL ASSY14	4	3						4	3	2					1	3	1				
FUEL ASSY15	4	1	1	1	1			6	2	1	1	1	0	1	3	1	1				

5. Conclusion

Investigated are the effects of variations in the amplitude and frequency of the core plate motions on the resultant spacer grid impact loads. The results show that changing the natural frequency has negligible effect but changing the amplitude of the input motions has a significant effect on grid impact loads. In other words, the spacer grid impact loads are much more sensitive to changes of amplitude than of frequency contents in input motions. Therefore, time history analysis for a shifted case in not necessary to get the core responses under the seismic excitation for design loads.

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