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DYNAMIC RESPONSE OF THE HIGH FLUX ISOTOPE REACTOR STRUCTURE CAUSED BY NEARBY HEAVY LOAD DROP

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DYNAMIC RESPONSE OF THE HIGH FLUX ISOTOPE REACTOR STRUCTURE CAUSED BY NEARBY HEAVY LOAD DROP[1]

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ABSTRACT

A heavy load of 50,000 lb is assumed to drop from 10 ft above the bottom of the High Flux Isotope Reactor (HFIR) pool at the loading station. The consequences of the dynamic impact to the bottom slab of the pool and to the nearby HFIR reactor vessel are analyzed by applying the ABAQUS computer code. The results show that both the HFIR vessel structure and its supporting legs are subjected to elastic disturbances only and, therefore, will not be damaged. The bottom slab of the pool, however, will be damaged to about half of the slab thickness. The velocity response spectrum at the concrete floor next to the HFIR vessel as a result of the vibration caused by the impact is obtained. It is concluded, that the damage caused by heavy load drop at the loading station is controlled by the slab damage and the nearby HFIR vessel and the supporting legs will not be damaged.

1. INTRODUCTION

The purpose of the present calculation is to evaluate the consequence of an accidental drop of a heavy container and its contents on the bottom floor of the pool of the High Flux Isotope Reactor (HFIR) (Fig. 1a). Specifically, this calculation is intended to estimate whether the impact and vibration induced by the heavy load drop may damage the nearby reactor vessel and the attached structural parts. The distance between the point of load drop to the reactor is approximately 15 ft. The total weight of the container and the contents is approximately 50,000 lb. The present calculation is a sequel of an earlier calculation that only analyzed the potential damage to the bottom concrete slab of the HFIR pool. That calculation can be obtained from the RRD Document Control Center. The effect of the pool water that surrounds and interacts with the reactor vessel is neglected in this dynamic analysis. The stress induced by the static weight of the heavy load is also neglected. All the numerical calculations are carried out by applying the ABAQUS finite element code.

The problem is modeled and simplified to an equivalent two-dimensional plane strain problem. The model consists of the concrete slab and the concrete wall of the pool, the idealized heavy load, the reactor vessel, and its supporting legs. The total heavy load is also idealized to an equivalent two-dimensional load. The two-dimensional load is assumed to be the total load divided by the width of the container and further reduced to 75%. The 75% reduction is assumed because of the three-dimensional effect of the reinforced concrete slab.

To construct a two-dimensional model, the total weight of the reactor vessel is assumed to be distributed across the width of the lower portion of the vessel of 33 in. It is conservative and over-estimates the two-dimensional mass of the vessel. The vessel mass is then approximately modeled by four lumped mass points attached along the vertical axis of the vessel. The lower vessel and the supporting legs are idealized by using equivalent steel beam elements.

In the numerical calculation, the reinforced concrete slab and wall are assumed to be monolithic and a homogeneous piece of solid. The solid is assumed to be equally as strong in tension as in compression. The same strength in compression as in tension was

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also adopted in an extensive NUREG report on drop and seismic evaluations for the H. B. Robinson and Vermont Yankee nuclear power plants (ref. 1). Concrete failure strain is assumed to be 0.45%, concrete density 145 lb/ft^3, and concrete yield stress 4 ksi (ref. 2).

The stress induced by static load of the reactor is believed to cause only second-order effects as compared to the effect caused by the kinetic energy generated by the impacting heavy mass. As observed in Fig. 1d, the acceleration at point of impact has a maximum value of 60,000 in./sec^2 that is 60,000/386 = 155 times the gravitational acceleration. The static weight is, therefore, negligible. Interaction of the reactor vessel with its surrounding water only increases a fraction of the effective mass, the added mass effect. It is neglected.

2. COMPUTATION AND ANALYSIS

The HFIR vessel dimension and weight distribution are shown in the following:

Vessel inner diameter	—	96 in.
Vessel wall thickness	—	3 in.
Lower vessel diameter	—	33 in.
Lower vessel wall thickness	—	1.5 in.
Vessel head weight	—	28,000 lb
Vessel proper	—	69,000 lb

The impact solution of the drop problem is obtained by using the ABAQUS computer code. In the ABAQUS input file, it is assumed that the reinforced concrete is homogenous and capable of carrying compressive stress as well as tensile stress. This is a reasonable assumption because the reinforced slab and wall are designed by assuming the concrete to be capable of resisting compressive stress only and the reinforcement steel at the tensile side capable of carrying tensile loading. The tensile steel is usually designed so that the neutral axis is located approximately at the midplane, and the deficiency of the concrete to carry tensile stress is replaced by an equivalent amount of reinforcement steel.

The heavy weight of 50,000 lb that drops from a height of 10 ft will result in an end velocity of 430 in./sec at the moment of impact to the concrete slab. The maximum permissible lifting height of 10 ft without causing severe damage of the pool floor was concluded from the earlier report.

The complete two-dimensional model includes the concrete slab, concrete wall, HFIR vessel, and supporting legs. Numerical solutions of the lower vessel stress and the stress of the supporting legs are obtained. For the simplified model, the HFIR vessel is replaced by the weight of the vessel. The mass of the vessel weight is attached to the concrete slab with no detailed vessel model. It is a simplified model, because it will generate approximately the same natural frequencies and, therefore, the responses. Numerical solutions of this simplified model are obtained.

2.1 Two-Dimensional Impact Solution—With Vessel Model

For the two-dimensional model, the reactor vessel is supported by the lower vessel wall and by the two supporting legs. It is located at one end of the pool with a lower elevation as compared with the main HFIR pool. The heavy load is dropped on the concrete slab of the main pool.

2.1.1 Time History of the Heavy Load. Figures 1b through 1d show, respectively, the vertical displacement, velocity, and acceleration of the impact load point. It is seen that the impact begins at time equal to 0.005 sec, because initially the heavy load is set slightly above the slab. The object remains in contact with the slab until time equal to 0.015 sec. After 0.015 sec, the object bounces back and separates from the slab. The amount of plastic deformation printed to the slab is obtained. If we use a strain of 0.45% to be the failure strain, the slab should have been damaged in slightly more than half of its thickness.

2.1.2 Stress and Acceleration Distribution at Time Equal to 0.0214 sec and at Time Equal to 0.0404 sec. The maximum responses occur at time approximately equal to 0.0214 sec. At this instant, the Mises stress and tensile stresses s_{11} and s_{22} are obtained everywhere in the model. The acceleration distributions a_1 and a_2 are also obtained. These results show the maximum values at the concrete slab where the reactor is located.

At time equal to 0.0404 s, those distributions at the concrete slab near the reactor begin to unload. The Mises stress and tensile stresses s_{11} and s_{22} as well as the accelerations a_1 and a_2 are obtained everywhere in the model.

2.1.3 Time History Solution of the Stresses at Lower Vessel Wall and at Supporting Legs. This section gives an estimate of the possible maximum stresses that may occur at the lower reactor vessel wall and at the supporting legs. The results show that the stresses are within the elastic range. None of these parts will be damaged.

Figures 2a and 2b show the stress vs time curves of the lower vessel wall and of the supporting legs, respectively. The maximum numerical values and time instants are tabulated below:

Parts name	Time, sec	Stress, ksi	Element
Lower vessel wall	0.043	–7.0	4318
	0.075	7.0	
Supporting leg	0.043	–22.0	4404
	0.075	22.0	

The yield stress is 36 ksi and the 10-ft drop will not damage the vessel and its legs.

2.1.4 Time History Solution of the Responses at the Surface of HFIR Base Slab. At the surface of the concrete slab where the HFIR reactor is located, the time history solutions of displacement, velocity, and acceleration at node point 785 are shown in Figures 3a through 3f. Node point 785 is located close to the lower vessel wall.

Of particular interest, the acceleration histories shown in Figs. 3e and 3f at very early time exhibit very-high-frequency acceleration waves at the wave fronts for both horizontal and vertical components. It is a characteristic feature for the impact solution. The impact loading history can be represented from the heavy load point acceleration Fig. 1c. It is approximately a pulse. From the Fourier analysis, the step function is composed of high-frequency components that, in turn, propagate through the structure and are shown in the earlier time histories.

2.1.5 Floor Velocity Response Spectrum. The acceleration time histories shown in Figs. 3e and 3f are numerically integrated by using the following convolution integral:

$$x(t) = \frac{1}{\omega\sqrt{1-\zeta^2}} \int_0^t a(t')\exp[-\zeta\omega(t-t')]\sin\left[\omega\sqrt{1-\zeta^2}\,(t-t')\right] dt' .$$

In the above equation, ω is the circular natural frequency of a simple one degree of freedom oscillator, ζ is the damping ratio, and $a(t)$ is the ground acceleration time history. The equation of motion is

$$\ddot{x}\,(t) + 2\,\zeta\,\omega\,\dot{x} + \omega^2\,x = -a(t)\ .$$

The velocity spectrum is the maximum value of the integral $x(t)$ over the time interval vs the natural frequency ω. The horizontal and vertical spectra are plotted in Figs. 4a and 4b, respectively, for 5% and 10% dampings.

2.2 Simplified Two-Dimensional Model

A simplified two-dimensional model is built to replace the vessel by mass points. The vessel and the supporting legs are replaced by equivalent mass points that are distributed across the central section of the concrete slab on which the HFIR vessel is located. The purpose of this simplification is to confirm that it produces similar velocity response spectrum plots. The corresponding time histories for the midsection acceleration are plotted in Figs. 5a and 5b. The velocity response spectra are plotted in Figs. 6a and 6b.

Figures 5a and 5b are the response time histories of the center of the slab of the vessel at node 783. Figures 6a and 6b are the floor velocity spectra for this simplified model. It is observed that Figs. 6a and 6b are similar to the spectra Figs. 4a and 4b with approximately equal spectrum responses.

3. RESULTS AND CONCLUSIONS

In Figs. 2a and 2b, the impact-induced stresses in the lower HFIR vessel wall and in the HFIR vessel supporting legs are all elastic. No damage of either part is expected. For example, you may say that the spectra in Figs. 4a, 4b, 6a, and 6b are of the same order of magnitude as that which might be associated with a moderate-sized earthquake.

4. REFERENCES

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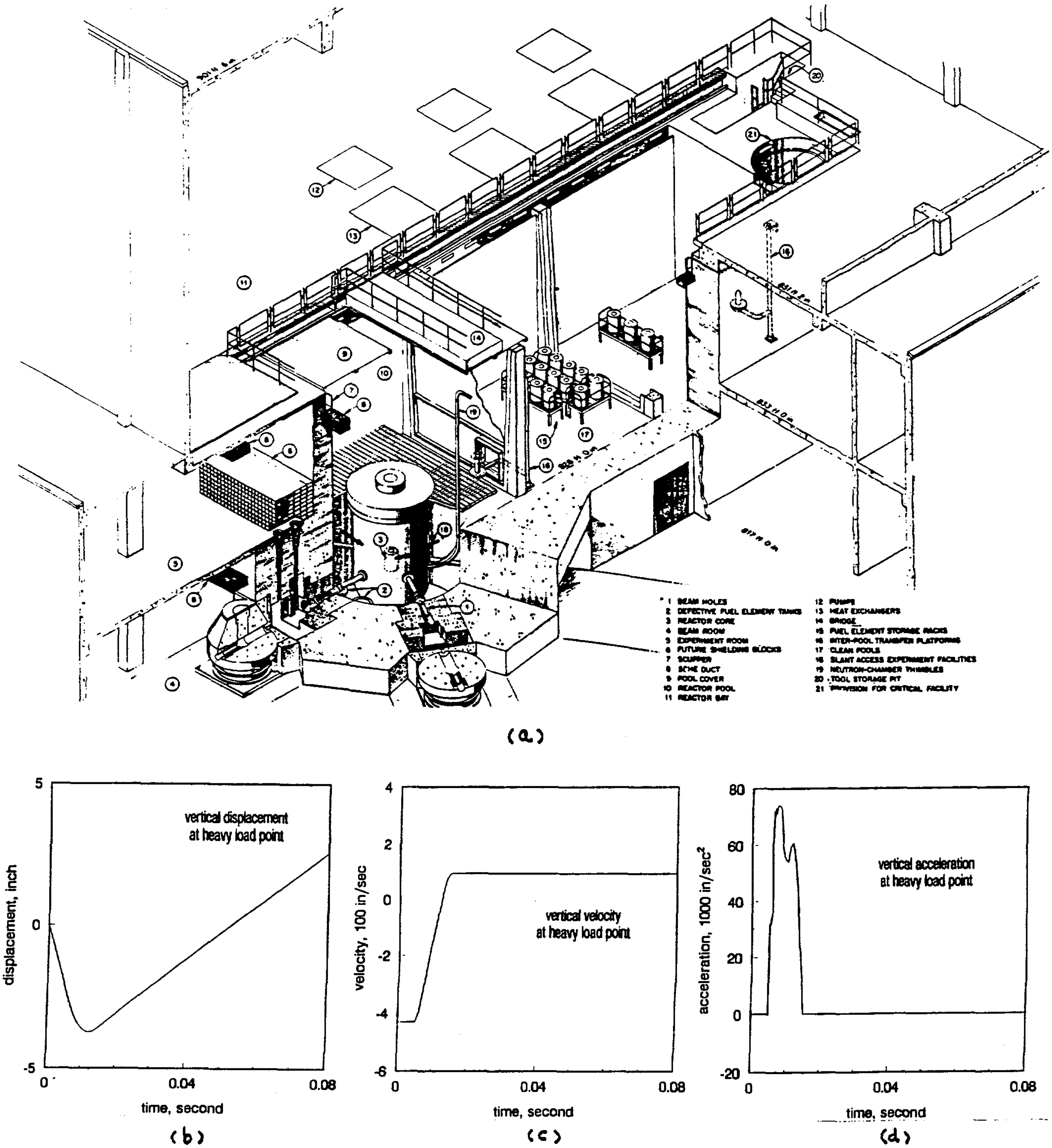


FIG. 1A–D. HIGH FLUX ISOTOPE REACTOR AND TIME HISTORIES OF THE HEAVY LOAD POINT: (A) HIGH FLUX ISOTOPE REACTOR, (B) DISPLACEMENT, (C) VELOCITY, AND (D), ACCELERATION. THE LOAD POINT TOUCHES THE SLAB AT TIME EQUAL TO 0.005 SEC AND LEAVES AT 0.015 SEC. THE INITIAL CONTACT TO THE SLAB IS 0.005 SEC, BECAUSE THE INITIAL HEIGHT OF THE HEAVY LOAD IS SET SLIGHTLY ABOVE THE SLAB. A PULSE OF DURATION APPROXIMATELY 0.01 SEC HAS THE SHAPE SHOWN IN 7.2C.

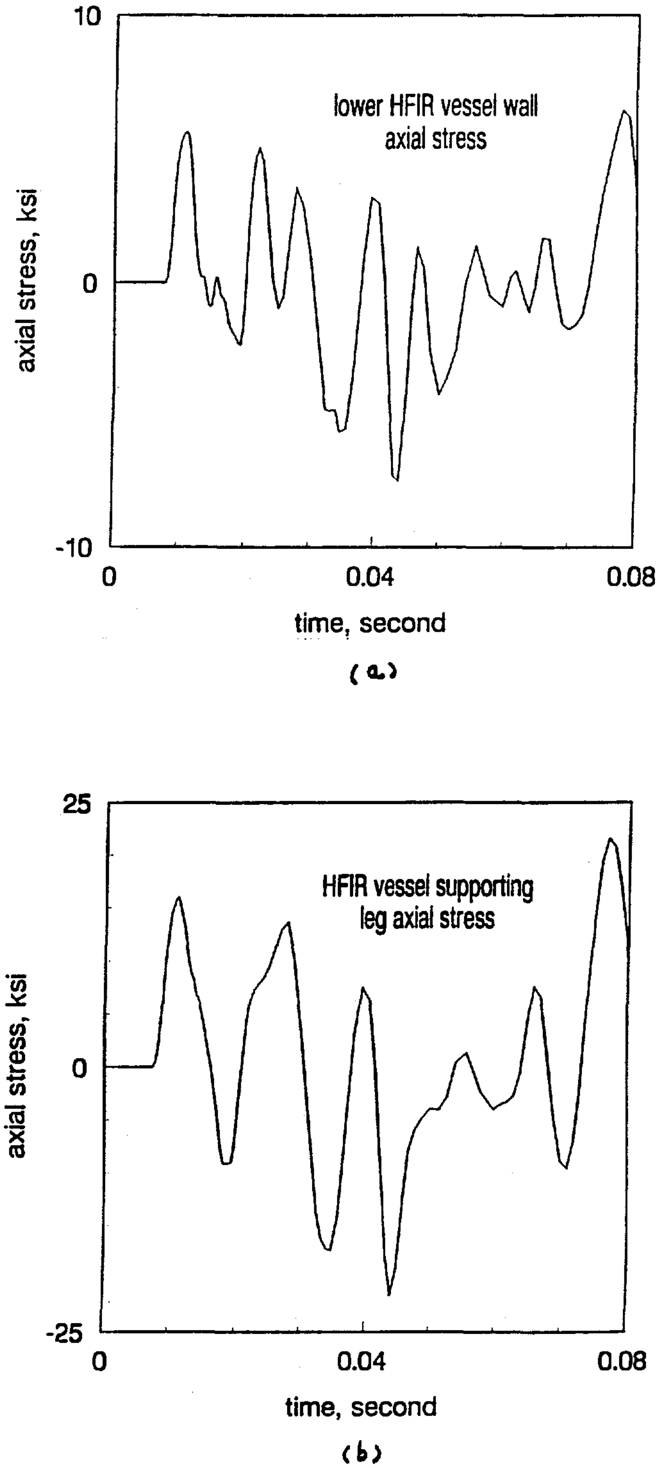


FIG. 2A–B. FOR THE TWO-DIMENSIONAL MODEL, THE TIME HISTORIES OF THE TENSILE STRESS (A) FOR THE LOWER HFIR VESSEL WALL AT ELEMENT 4318 AND (B) FOR THE VESSEL SUPPORTING LEG AT ELEMENT 4404.

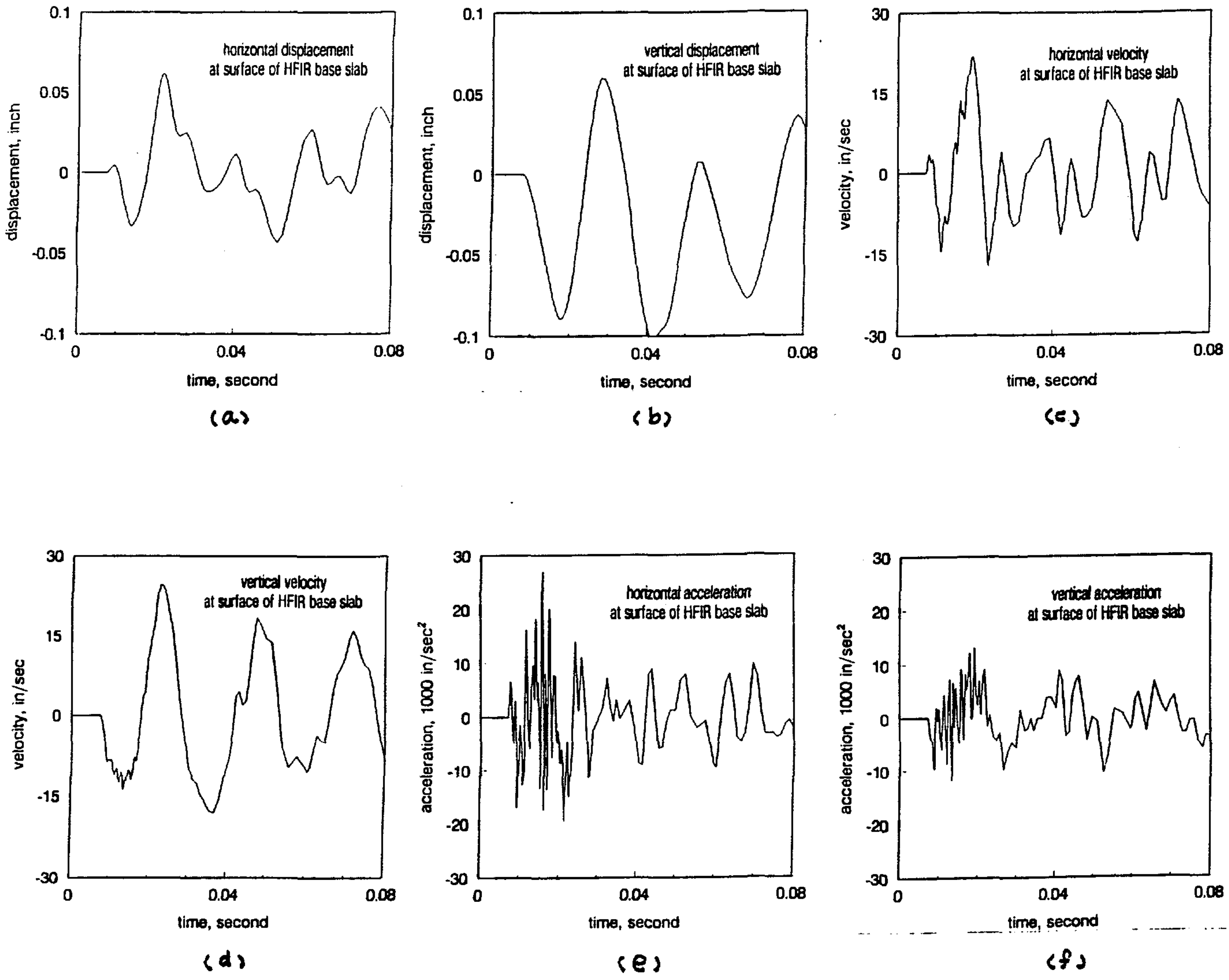


FIG. 3A–F. THE MAXIMUM STRESSES ARE 7.0 KSI FOR PART (A) AND 23.0 KSI FOR PART (B). THE TIME HISTORIES FOR THE TWO-DIMENSIONAL MODEL AT THE SURFACE OF THE REACTOR SUPPORTING CONCRETE SLAB NEAR THE HFIR LOWER VESSEL WALL AT NODE 785: (A) HORIZONTAL DISPLACEMENT, (B) VERTICAL DISPLACEMENT © HORIZONTAL VELOCITY, (D) VERTICAL VELOCITY, (E) HORIZONTAL ACCELERATION, AND (F) VERTICAL ACCELERATION. HIGH-FREQUENCY ACCELERATION WAVES ARE OBSERVED NEAR THE WAVE FRONT SHOWN IN (E) AND (F).

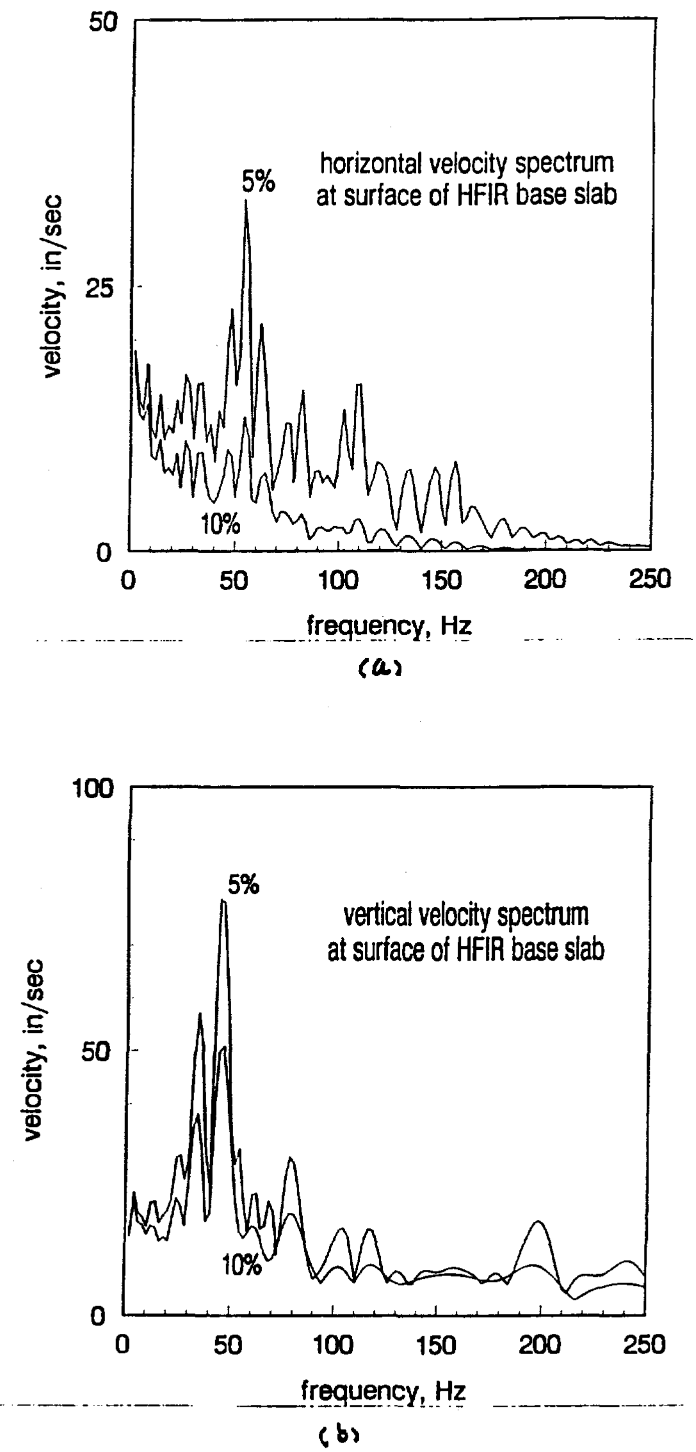
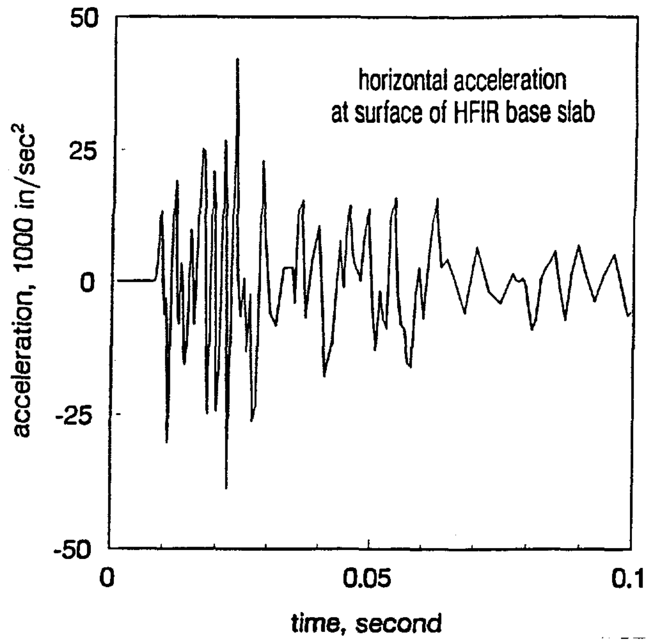
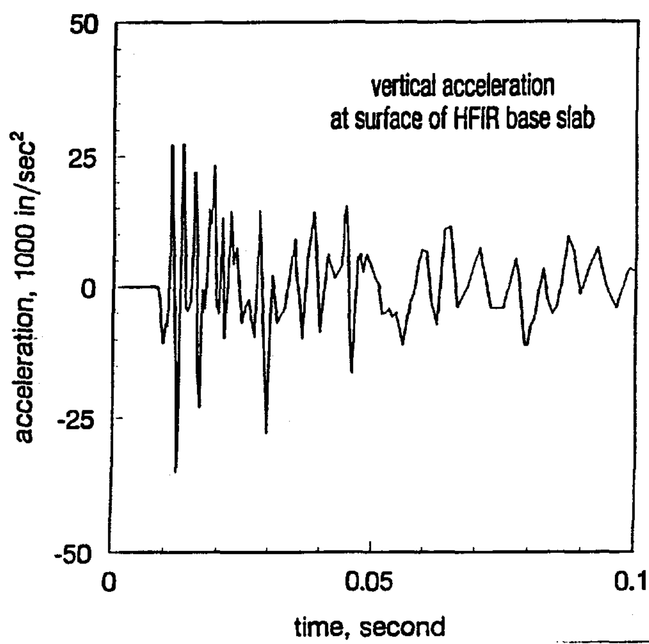


FIG. 4A–B. (A) HORIZONTAL VELOCITY RESPONSE SPECTRUM AND (B) VERTICAL VELOCITY RESPONSE SPECTRUM FOR THE TWO-DIMENSIONAL IMPACT MODEL AT NODE 785 NEAR THE HFIR LOWER VESSEL WALL ON THE SURFACE OF THE CONCRETE SLAB.



(a)



(b)

FIG. 5A–B. THE MAXIMUM STRESSES ARE 7.0 KSI FOR PART (A) AND 23.0 KSI FOR PART (B). THE TIME HISTORIES FOR THE SIMPLIFIED TWO-DIMENSIONAL MODEL AT THE SURFACE OF THE REACTOR SUPPORTING CONCRETE SLAB NEAR THE HFIR LOWER VESSEL WALL AT NODE 785: (A) HORIZONTAL ACCELERATION, AND (B) VERTICAL ACCELERATION. HIGH-FREQUENCY ACCELERATION WAVES ARE OBSERVED NEAR THE WAVE FRONT SHOWN IN (A) AND (B).

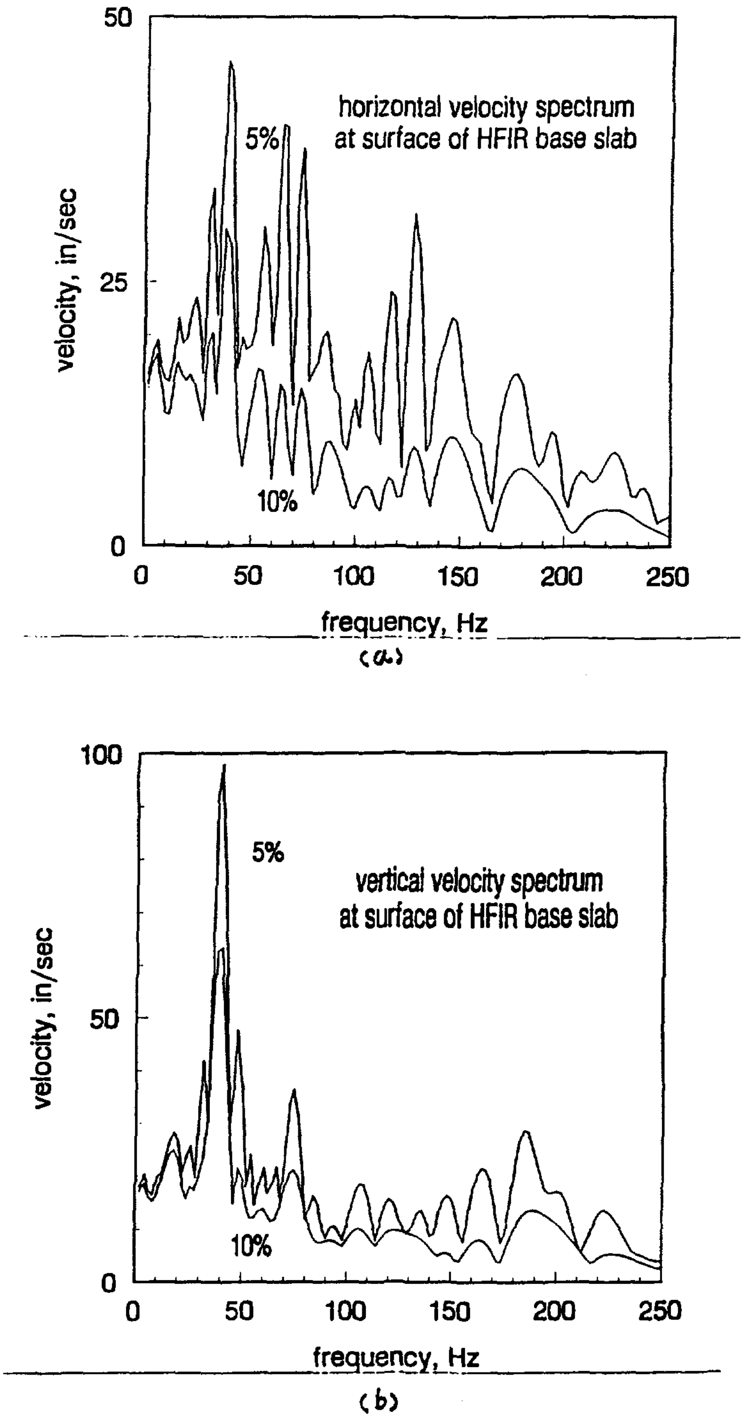


FIG. 6A–B. (A) HORIZONTAL VELOCITY RESPONSE SPECTRUM AND (B) VERTICAL RESPONSE SPECTRUM FOR THE SIMPLIFIED TWO-DIMENSIONAL IMPACT MODEL AT NODE 785 NEAR THE HFIR LOWER VESSEL WALL ON THE SURFACE OF THE CONCRETE SLAB.