SOIL-STRUCTURE INTERACTION METHODS SUMMARY REPORT

C.A. MILLER

THE CITY UNIVERSITY OF NEW YORK
Under Contract to the
STRUCTURAL ANALYSIS GROUP
of
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

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1.0 Introduction

The objective of the work reported here was to implement three computer programs on the Brookhaven National Laboratory (BNL) CDC 7600 computer system. The three programs are centered about the soil-structure interaction problem in seismic analyses.

The report is comprised of four volumes. One for each of the three codes and this summary volume. In this volume the capabilities of each of the codes are discussed (Section 3.0) following a general overview of the seismic analysis problem indicating how the codes fit into the total problem (Section 2.0). Application of the three codes to a sample problem is discussed in Section 4.0

2.0 Overview of Problem

A general overview of the seismic analysis problem is shown on Figure 1. In general one wishes to compute the motion (or floor response spectra) of selected points within a nuclear power plant caused by a criteria seismic motion specified at some elevation in the free field.

The criteria motion may not be specified at the elevation required to perform the response analysis. There is a need therefore to generate consistent motions throughout the free field. It is generally assumed that the energy released from a seismic event travels to the site in the underlying bedrock. Locally the energy thus travels as horizontal shear waves up through the soil column to the plant. Consistent motions therefore are motions at all elevations generated from the same input motion at bedrock. The usual procedure is to deconvolute the criteria motion to calculate the bedrock motion and then to use this motion as input to the base of a shear beam to calculate the motion at any other elevation. Soil Layer Amplification of Vertical Shear Waves (SLAVE) Code performs these calculations.

As indicated in Figure 1, there are two methods available to perform the facility response calculations. The first possibility is to model the free field (down to bedrock) with a finite element mesh and use the bedrock motion as input to the base of the model. The structure may be modeled either with finite elements or with an equivalent stick model appropriately connected to the free field mesh. Stress Waves in Layered Arbitrary Media (SLAM) Code performs this type of analysis.

The second type of response analysis (lumped parameter) uses the stick model of the facility and springs and dampens to reflect the coupling

of the structure to the free field. The free field motion at the level of the facility foundation is used as the seismic disturbance. Structure In Media (SIM) Code performs this type of analysis.

3.0 Code Capabilities

The capabilities of each of the three codes are discussed in this Section.

3.1 SLAVE Code

SLAVE Code utilizes an analytic solution to generate accelerograms at any elevation in a soil column consistent with an input accelerogram at a specified elevation. The soil column is treated as a shear beam of material represented with a linear damped constitutive law. The parameters in the constitutive law may be specified either as constants or as functions of the shear strain magnitude. In the latter case an iterative solution is carried out so that the correct shear strain is used in developing the soil properties.

In addition to control parameters input to the code consists of the criteria accelerogram and soil properties. Output from the code consists in accelerogram and response spectra at all specified locations. These may be: listed; plotted on line; Calcomp plotted; punched on cards; and/or stored on tape.

3.2 SLAM Code

SLAM Code is a large finite element program that treats the two-dimensional (plane or axisymmetric) wave propagation through non-linear layered materials and the interaction of these motions with a flexible structure embedded within or on the soil. Some of the general capabilities of SLAM Code that are of interest in seismic analyses are as follows:

- (a) The free field is modeled with finite elements and may include arbitrary layering and non-linear material properties.
- (b) The embedded structure can be represented either by finite elements or by its rigid body and elastic free-free mode of vibration.
- (c) Potential separation and/or sliding between the structure and the soil may be treated by means of special "crack" elements.
- (d) Non reflecting or "quiet" boundaries may be included to minimize the required size of meshes.

The solution in SLAM Code is carried out in the time domain (i.e., numerical integration of the equations of motion). Output from the code consists of motion histories at specified nodes in the free field and structure, stresses in specified elements in the free field, and response spectra at selected location.

3.3 SIM Code

SIM Code determines the response of a structure embedded in a soil media to a specified dynamic disturbance in the media. The structure is modeled as a series of lumped masses, and elastic beams which may be interconnected with elastic springs. Each node has two degrees of freedom: horizontal translation; and rotation (vertical displacements are not considered). The free field disturbance is specified in terms of an accelerogram, the scale of which may vary with depth. Soil/structure interaction forces include both forces at the base and those developed along the side walls for embedded structures.

Output from SIM Code consists of displacement time histories and/or response spectra at specified locations within the structure.

4.0 Sample Problem

A series of problems have been run to illustrate the use of the three codes. The FFTF Reactor Containment Building is used for this sample problem.

The criteria pulse is specified at the surface with bedrock at 400 feet below the surface. The soil layer is fairly uniform having a shear modulus of 1.156×10^7 psf and a hysteretic damping ratio of 0.01 (i.e., 1% of critical). The response spectra of the criteria surface pulse is shown in Figure 2. This response spectra is an on-line plot generated as part of the SLAVE Code run. SLAVE Code then generated consistent histories at 40 feet, 80 feet and 400 feet (bedrock). The resulting spectra is shown on Figures 3, 4 and 5.

The Reactor Containment Building and stick model of the building is shown in Figure 6. The FFTF criteria surface pulse was used as input to the stick model and SIM Code used to generate response spectra. The response spectra at node 15 (reactor support) is shown in Figure 7.

The same problem was then run with SLAM Code. The mesh shown in Figure 8 was used. As may be seen, an axis of asymmetry is taken through the center line of the structure. A quiet boundary is placed 400 feet from the center of the structure and the bedrock motion is input at the base. The resultant response spectra at the reactor support is shown in Figure 9. As may be seen, this is quite similar to that obtained with SIM Code.

Figure 1. Overview of Codes

IFTF CRITERIA PULSE= 0.25-G+S, -D1=-0.01 SEC
 NOISE POINT= 1 EQUIPMENT DAMPING= 2.00000E-02
 RESPONSE SPECTRA IN G/S

Figure 2

FFTF CRITERIA PULSE , 0.25 G'S , DT= 0.01 SEC
 NODE POINT= 1 EQUIPMENT DAMPING= 2.00000E-02
 RESPONSE SPECTRA IN 0.5

DEPTH 1

FFTF CRITERIA PULSE , 0.25 G'S , DT= 0.01 SEC
 NODE POINT= 1 EQUIPMENT DAMPING=

2.00000E-02

DEPTH 2

RESPONSE SPECTRA IN G.S

FFTF CRITERIA PULSE . 0.25 G'S . DT= 0.01 SEC
 NODE POINT= 1 EQUIPMENT DAMPING= 2.0000E-02 DEPTH 3
 RESPONSE SPECTRA IN G.S

Figure 6. FFTF Reactor Containment Building Sample Problem #1

SAMPLE PROBLEM 1 ...FFTF, FLEXIBLE STRUCT., WALL INTERACTION
 NODE POINT= 15 EQUIPMENT DAMPING= 2.00000E-02

RANGE IN FEET
0.00 50.00 100.00 150.00 200.00 250.00 300.00 350.00 400.00
MESH PLOT

STRUCTURE
"STICK" MODEL
AS SHOWN IN
Fig 2

AXIS OF ASYMMETRY

				69	90	111	132	153	174	195
				70	91	112	133	154	175	196
				71	92	113	134	155	176	197
				72	93	114	135	156	177	198
				73	94	115	136	157	178	199
1	18	35	52	74	95	116	137	158	179	200
2	19	36	53	75	96	117	138	159	180	201
3	20	37	54	76	97	118	139	160	181	202
4	21	38	55	77	98	119	140	161	182	203
5	22	39	56	78	99	120	141	162	183	204
6	23	40	57	79	100	121	142	163	184	205
7	24	41	58	80	101	122	143	164	185	206
8	25	42	59	81	102	123	144	165	186	207
9	26	43	60	82	103	124	145	166	187	208
10	27	44	61	83	104	125	146	167	188	209
11	28	45	62	84	105	126	147	168	189	210
12	29	46	63	85	106	127	148	169	190	211
13	30	47	64	86	107	128	149	170	191	212
14	31	48	65	87	108	129	150	171	192	213
15	32	49	66	88	109	130	151	172	193	214
16	33	50	67	89	110	131	152	173	194	215
17	34	51	68							

QUIET BOUNDARY

← CRITERIA MOTION

Figure 9