NAURAL SEISMIC BASE ISOLATION SYSTEM FOR RCC SRTCTURES

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ABSTRACT

Generally seismic isolation is achieved by using laminated rubber bearings, lead bearings etc. as a supporting elements in structures. Very little work has been performed using soil as a base isolation media. Experiments and analytical work has been performed and found encouraging results. Details of this work are presented in this paper.

INTRODUCTION

Soil has very typical engineering properties. The soil in static condition and the same soil in dynamic condition exhibit entirely different engineering properties. Shear modulus of soil in static condition and that in dynamic condition varies largely. The soil properties can be altered by adding fibers or membranes. M.K. Yegian and U. Kadakal [1] have performed experimental work by using geo-synthetic material and shown that response of the structure can be altered. Fu Lin Zhou, et al., 2004 [2] have performed experiments on structures resting on sand layer. The properties also get affected by presence of water in the soil. Keeping the above facts in view, soil (river sand) was used as a base isolation material. Experiments were conducted on a RCC frame model placed on a layer of soil, a layer of soil mixed with water and a layer of soil provided with geo-membrane to evaluate the isolation effect under seismic conditions.

River sand having engineering properties shown in Table 1 was used in the experiments. Geo-membrane was used with a soil layer to know the effect of membrane on the performance of a soil layer.

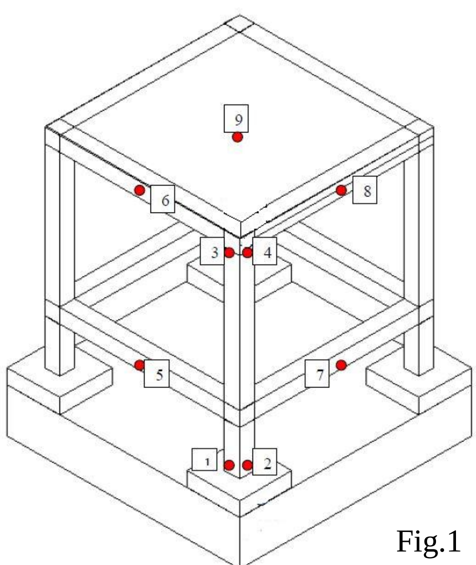

Fig.1 Location of accelerometers

Table 1: River sand properties

Property	Value	Property	Value
Gravel	5.6%	Cu	7.37
Coarse sand	19.4%	Cc	1.12
Medium Sand	53%	γdmax	1.71g/cc
Fine Sand	17.6%	γdmin	1.40g/cc
Silt + Clay	4.4%	Sp.gravity	2.66
D60	1.18mm	emax	0.77
D10	0.16mm	emin	0.48
D30	0.46mm		

ISOLATED FOOTING MODEL

RCC frame structure model of size 1.2 x 1.2 x 1.5 m height having column and beam c/s size of 0.1 x 0.1 m, roof slab thickness of 0.05 m and isolated footings of 0.3 x 0.3 x 0.1m was prepared as shown in Fig. 1 & 2(a). A metallic box of size 2.0 x 2.0 x 1.2 m height, filled with sand/ sand with geo-membrane layer with height of 300mm was used in the experiments. The model was kept on the soil layer. The test set up is shown in Fig 2(b).

Experiments were conducted [3] to see the effect of such layer on the structure. The model was tested on shake table and results were obtained.

Resonance search tests were conducted on the model with sinusoidal motion of 0.1g for fixed base (FXISO) model and 0.2g for other models with sweep rate of 1 octave/min in horizontal directions X, Y and vertical direction Z and natural frequencies of the model were established. Table 2 shows the frequencies of the model in different base conditions. It is seen that as compared to fixed base model frequencies, the frequencies of the model supported on dry soil, wet soil and soil with geo-membrane are reduced in all the three directions. The reductions in frequencies with dry sand are up to 16.16% and that with wet sand plus geo-membrane are up to 44.31%. The reduction in frequencies increases with geo-membrane.

(a)

(b)

Fig.2 a) Isolated footing model b) Shake table test set up

Table 2: Variation in natural frequency of isolated footing model from experimental results

Model condition	Frequency			Percentage variation		
	X	Y	Z	X	Y	Z
Fixed base (FXISO)	4.39	4.27	12.54			
Supported on a layer of dry sand (ISODRY)	3.90	3.58	11.60	-11.16	-16.16	-7.50
Supported on a layer of dry sand + geo-membrane (IDSGM)	2.82	2.58	10.69	-35.76	-39.58	-14.75
Supported on layer of saturated sand (ISOWET)	3.09	3.10	10.46	-29.61	-27.40	-16.59
Wet sand + Geo-membrane (ISOWETG)	2.51	2.38	10.12	-42.87	-44.31	-19.30

Table 3 shows the variation in damping ratios, which are estimated from the experimental results. The damping ratios are increased in horizontal directions (X and Y directions) as compared to FXISO case. For dry sand condition, increase in damping is 154.64% & 119.42% in X & Y directions respectively. Similar result is obtained for dry sand with geo-membrane condition except increase in damping in Y direction by 78.64%. The values of increase in damping for wet sand with geo-membrane condition are 97.62% and 80.58% for X and Y directions respectively.

Table 3: Variation in damping ratio of isolated footing model from experimental results

Sr. No.	Model condition	Damping ratio		Percentage variation	
		X	Y	X	Y
1	Fixed base (FXISO)	1.04	1.27		
2	Supported on a layer of dry sand(ISODRY)	2.64	2.79	154.64	119.42
3	Supported on a layer of dry sand + geo-membrane (IDSGM)	2.66	2.27	156.19	78.64
5	Wet sand + Geo-membrane (ISOWETG)	2.05	2.30	97.62	80.58

Table 4: ISOLATED FOOTING MODEL – Accelerations for IS code zone III time history

	Z3-FXISO	Z3-ISODRY		Z3-ISOWET		Z3-ISOWETG		Z3- IDSGM	
	MAX ACC	MAX ACC	%variation	MAX ACC	%variation	MAX ACC	%variation	MAX ACC	%variation
Roof level accelerometers									
A3 (Dir-X, location-beam-column junction at Roof level)	9.15	5.95	-34.97	6.10	-33.33	6.30	-31.15	5.50	-39.89
A6 (Dir-X, location-at mid span of roof beam)	7.41	5.45	-26.45	5.01	-32.39	5.63	-24.02	4.66	-37.11
A4 (Dir-Y, location-beam-column junction at Roof level)	11.60	5.29	-54.40	6.52	-43.79	5.93	-48.88	5.82	-49.83

Table 4 shows the variation in accelerations recorded by accelerometers located at different point on the model during shake table testing. The accelerations were recorded for model conditions FXISO, ISODRY, ISOWET, ISOWETG and IDSGM for IS code[4] zone III time history . Comparison has been done between the fixed base model and that the model with soil layers. In general there is a reduction in the accelerations recorded by all accelerometers. In case of dry sand layer below the footing, the accelerations are reduced by 26.45% to 54.4% for roof level accelerometers. For saturated sand layer, the decrease in accelerations is 32.39% to 43.79%. Similarly, the reductions in accelerations are recorded for wet sand layer with geo-membrane, which vary from 24.02% to 48.88% and that for dry sand layer with geo-membrane from 37.11% to 49.83%.

FREQUENCY RESPONSE SPECTRA: ZONE III TIME HISTORY

Fig.3 shows frequency response spectra of accelerations recorded by accelerometer A3 located at roof level of the model in X direction. The response acceleration is lower for all the models, as compared to FXISO model. The lower accelerations indicate increase in damping due to soil layer. Also there is a shift in the frequency on the lower side.

The frequency response spectrum of accelerations recorded by accelerometer A4 located at roof level in Y direction is shown in Fig. 4. The accelerations are lower for all the models i.e. ISODRY, IDSGM and ISOWET as compared to FXISO model. There is a reduction in peak response acceleration for ISODRY, IDSGM and ISOWET model as compared to FXISO model. Also there is a shift in the frequency on lower side.

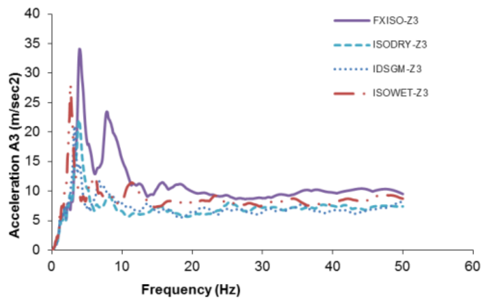

Fig. 3 – Spectra along X direction (A3)

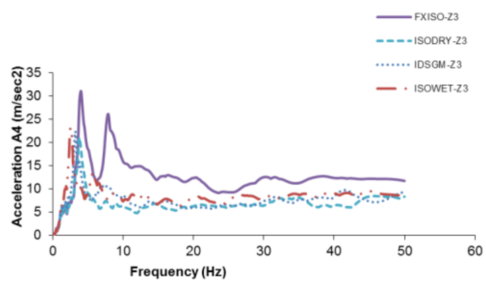

Fig. 4 – Spectra along Y direction(A3)

The response spectrum for acceleration recorded by accelerometer A6 located at roof level beam center to record the acceleration in the X direction is given in Fig. 5. The response accelerations for ISODRY, IDSGM and ISOWET are lower than the accelerations for FXISO case. There is a reduction in the peak response acceleration. There is a shift in the frequency on lower side as well.

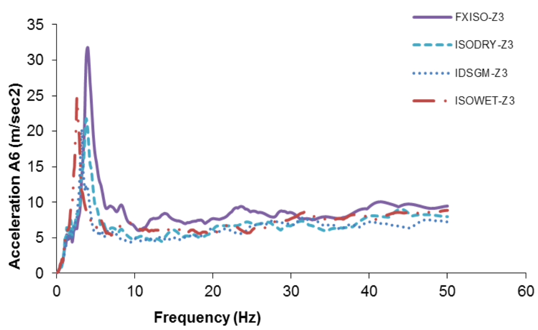

Fig. 5 Spectra along X direction(A6)

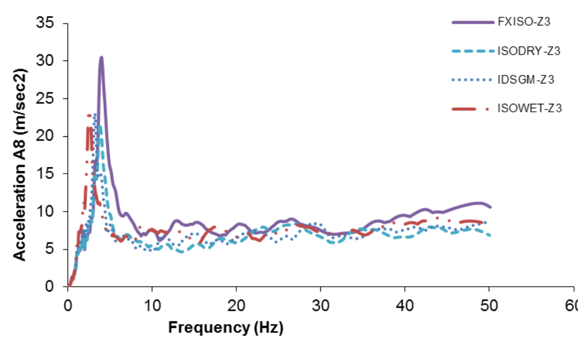

Fig. 6 Spectra along Y direction(A8)

The frequency v/s response acceleration spectrum for acceleration recorded by accelerometer A8 located at roof level beam to record acceleration in the Y direction are given in Fig. 6. The response accelerations are lower in case of models with soil layer as compared to the fixed base model. Also there is shift in the frequency on lower side as compared to fixed base frequency.

VARIATION IN TIME HISTORY

The graphs in Fig. 7 show the time histories of accelerometer A3 located at roof level, which has recorded the accelerations in X direction for FXISO model and other models with soil layer. It is seen from the above graphs that the accelerations reaching to the structure are less if a sand layer is introduced between the foundations and base of a structure. The total energy reaching to the structure is also less as the area of the time history of models with soil layer is less than the FXISO model.

The Fourier transform amplitudes plotted for A3 signal in Fig. 8 confirms that i) there is a reduction in the frequency of models on the sand layer as compared to the frequency of fixed base model ii) Fourier amplitude is on lower side in all the models and lowest in case of ISODRY model as compared to the amplitude of FXISO model. This conclusion corroborates with above response spectrum analysis.

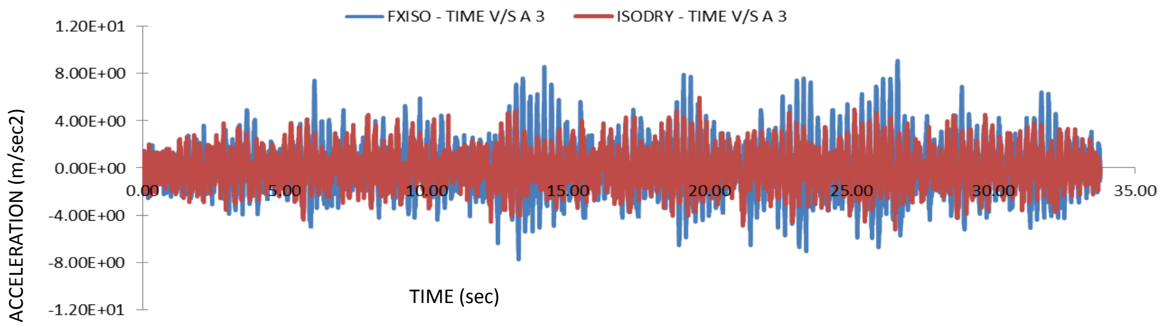

Fig.7(a) Time history along X direction (A3) for FXISO and ISODRY

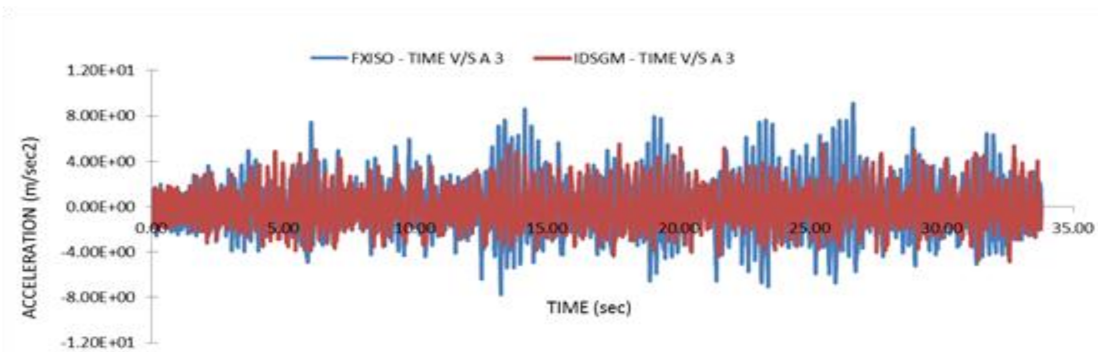

Fig.7(b) Time history along X direction (A3) for FXISO and IDSGM

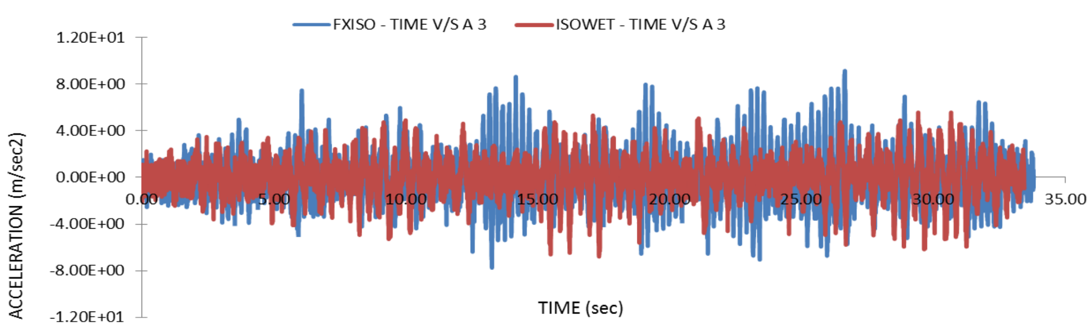

Fig.7(c) Time history along X direction (A3) for FXISO and ISOWET

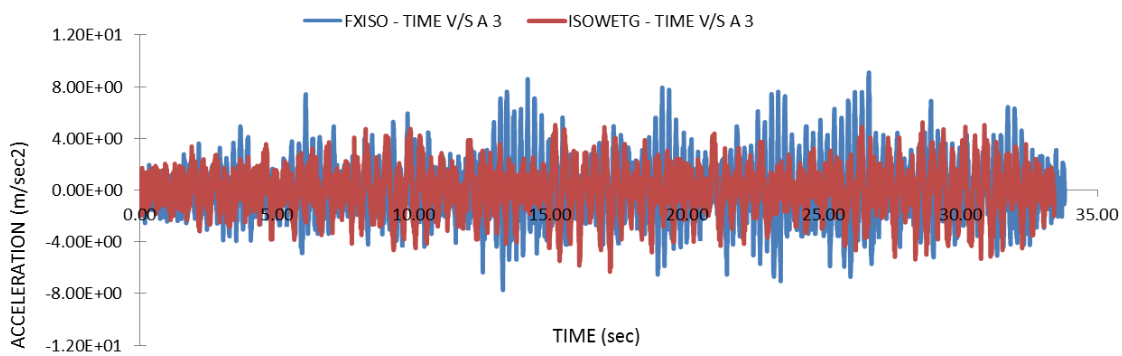

Fig.7(d) Time history along X direction (A3) for FXISO and ISOWETG

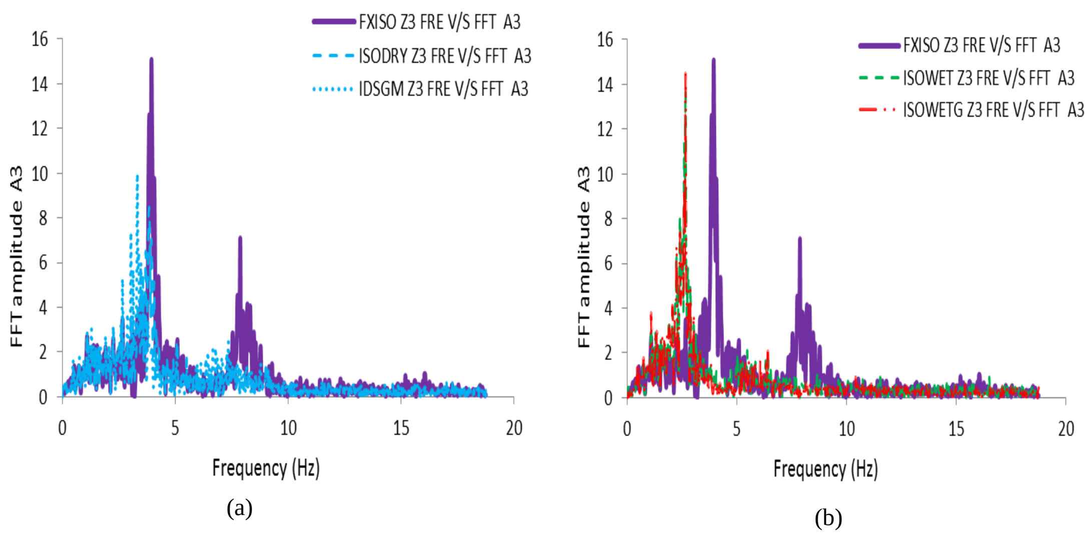

Fig. 8 Fourier spectra along X direction

ANALYTICAL RESULTS

The frequencies, obtained from the above response spectrum analysis and Fourier analysis, are matching with the free vibration tests as shown in the Table 6. This infers that the strains built in the soil are similar both in free vibration and force vibration tests. Using the displacements measured at top of the footings (Fig 9) strains are calculated with soil thickness of 300 mm and corresponding strain based G values are obtained using Fig 10, which is generated using modulus reduction theory [5].

$$\frac{G}{G_{\max}} = K(\gamma, PI)\left(\sigma_m^{'}\right)^{m(\gamma,PI)-m_0}$$

$$K(\gamma, PI) = 0.5\left\{1+\tanh\left[\ln\left(\frac{0.000102+n(PI)}{\gamma}\right)^{0.492}\right]\right\}$$

$$m(\gamma, PI) - m_0 = 0.272\left\{1-\tanh\left[\ln\left(\frac{0.000556}{\gamma}\right)^{0.4}\right]\right\}\exp(-0.0145PI^{1.3})$$

$$n(PI) = 0.0 \text{ for PI} = 0$$

Where PI plasticity index for sand layer.

Using the strain based G values and equations for stiffness parameters based on the half space theory given in table 5, stiffness is calculated [6].

Table 5. Spring Constants Coefficients for Foundations on Homogeneous Half-Space

Direction of Motion	Equivalent Spring Constant for Rectangular Foundation
Horizontal	$K_H = 2(1+\nu)G\,\beta_X\sqrt{(BL)}$
Rocking	$K_R = (G/(1-\nu))\,\beta_\psi\,BL^2$
Vertical	$K_v=(G/(1-\nu))\beta_v\sqrt{(BL)}$

Where -

ρ = mass density of soil

V_s = Shear wave velocity of soil medium

$G = \rho V_s^2$

ν = Poisson's ratio of soil medium

R = equivalent radius for rectangular foundation ($R= \sqrt{BL/\pi}$ for translation and $R= \sqrt[4]{4BL^3 / 3\pi}$ for rocking).

B = width of the foundation perpendicular to the direction of horizontal excitation

L = length of the foundation in the direction of horizontal excitation

β_x, β_ψ, and β_v are constants depending on ratio L/B

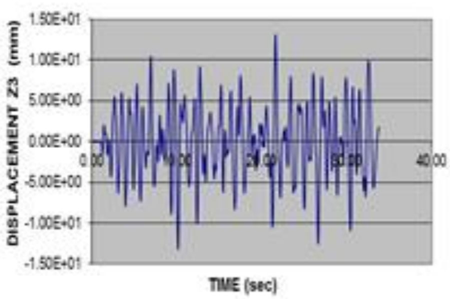

Fig. 9

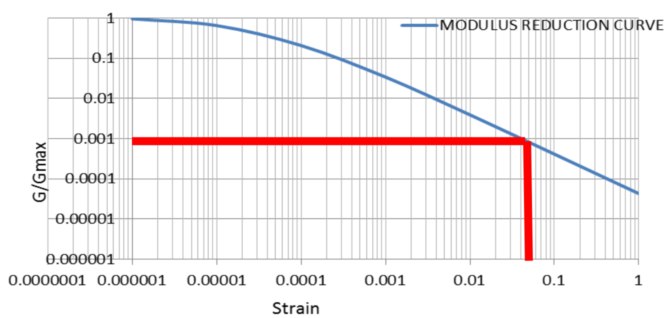

Fig. 10

FE model is generated by modeling beams and columns using beam elements and floor as shell elements. The footings are connected with soil springs evaluated above. The model was analyzed using SAP2000[7] software and the frequencies are tabulated in Table 6. Analytical frequencies for different models indicate that frequencies in all three directions for all the models on soil layer reduced as compared to fixed base model frequencies. This observation is similar to the one observed in experimental results.

Table - 6 Isolated footing model - Analytical & experimental frequencies

Model	Analytical		Experimental		Variation	
Type	X	Y	X	Y	X	Y
FXISO	4.27	4.27	4.39	4.27	-2.81	0.00
ISODRY	3.16	3.16	3.54	3.58	-12.03	-13.29
IDSGM	2.64	2.64	2.82	2.58	-6.82	2.27
ISOWET	2.97	2.97	3.09	3.10	-4.04	-4.38
ISOWETG	2.72	2.72	2.51	2.38	7.72	12.50

Comparison of analytical and experimental frequencies is shown in table 6. There is a good match between analytical and experimental frequencies the same are within 15% variation.

CONCLUSIONS

1. Introduction of soil layer between footing and hard foundation gives isolation effect to the structure. The degree of isolation will vary depending on the soil properties.
2. Maximum reduction in response acceleration is seen in case of ISODRY model followed by IDSGM, ISOWET and ISOWETG models.
3. Natural frequencies evaluated using stiffness based on the strain based G values. This approach can be used for evaluating natural frequencies of structure supported on soil layer used as a base isolation.

FUTURE STUDIES

The response has to be evaluated analytically and compared with the experimental results to complete the research work. An iterative procedure as explained in the text book [5] may be adopted and modifications may be suggested.

REFERENCES

1. Yegian M.K.& Kadakkal U.- Foundation isolation for seismic protection using a smooth synthetic liner. Journal Of Geotechnical And Geoenvironmental Engineering © ASCE / November 2004 / 1123.
2. Fu Lin Zhou, Zheng Yang, Wen Guang Liu And Ping Tan - New Seismic Isolation System For Irregular Structure With The Largest Isolation Building Area In The World (13 th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 1-6, 2004 Paper No.2349).
3. Dynamic soil structure interaction effects in multistoried structures on homogeneous soil and geo-synthetic reinforced soil. A BRNS research report 2009. NITK Suratkal, India.
4. IS 1893, 2002 Criteria for earthquake resistant design of structures (part 1 general provisions and buildings)
5. Cramer Steven L., Geotechnical Earthquake Engineering, 2007.
6. IAEA TECDOC 1347 - Consideration of external events in the design of nuclear facilities other than nuclear power plants, with emphasis on earthquakes.
7. SAP2000® V10 Linear and Nonlinear Static and Dynamic Analysis and Design of Three Dimensional Structures.