Effect of steel base blocks on frequency measurements on BS structure - 2

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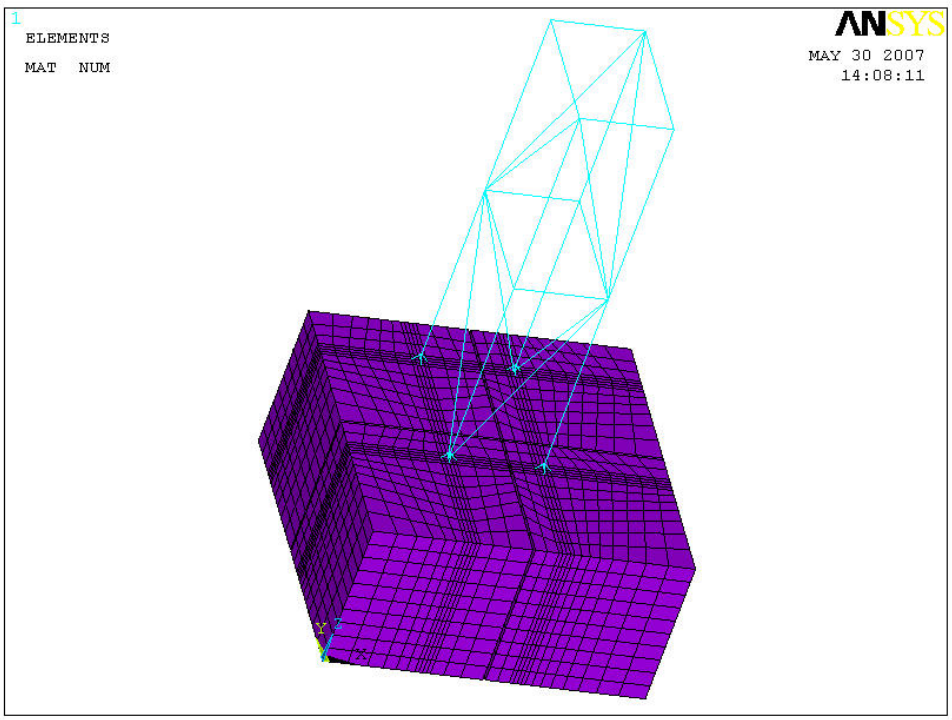
1. MOTIVATION

Tests on the behaviour of the structures continue to produce anomalous results. A test was made to check the motion of the structure at, or near, the feet where the structure is fixed to the blocks. The results are given in T070135, and show that the feet move in the "X" direction (see below) about a factor 0.1 less than points on about the middle ring of the structure. But the predictions from the existing FEA model say that the feet should only move about a factor 0.001 times the motion of the middle ring. This work explores whether that might be due to the blocks moving because they are not perfectly fixed on the floor.

2. MODEL

The model from previous work (T070117) was used. It consists of an aluminium alloy simple beam model, fixed to four blocks of steel (meshed with brick elements).

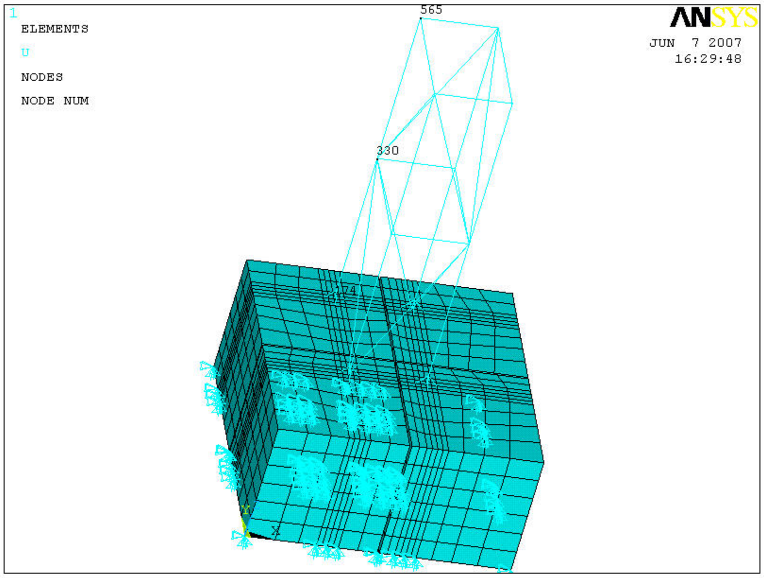


3. RESULTS

3.1 Initial result – concrete blocks fixed to floor

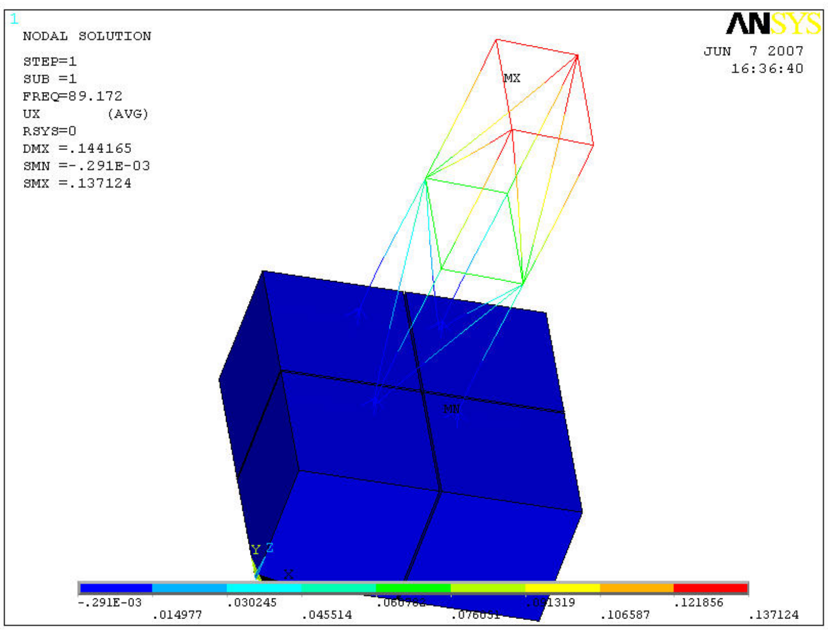
Frequencies below 200 Hz:

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	89.172	1	1	1
2	138.10	1	2	2
3	194.17	1	3	3



Three nodes were chosen along one leg.

NODE	X	Y	Z	THXY	THYZ	THZX
174	0.38000	1.0200	0.61000	0.00	0.00	0.00
330	0.38000	1.0200	1.4100	0.00	0.00	0.00
565	0.38000	1.0200	2.2100	0.00	0.00	0.00

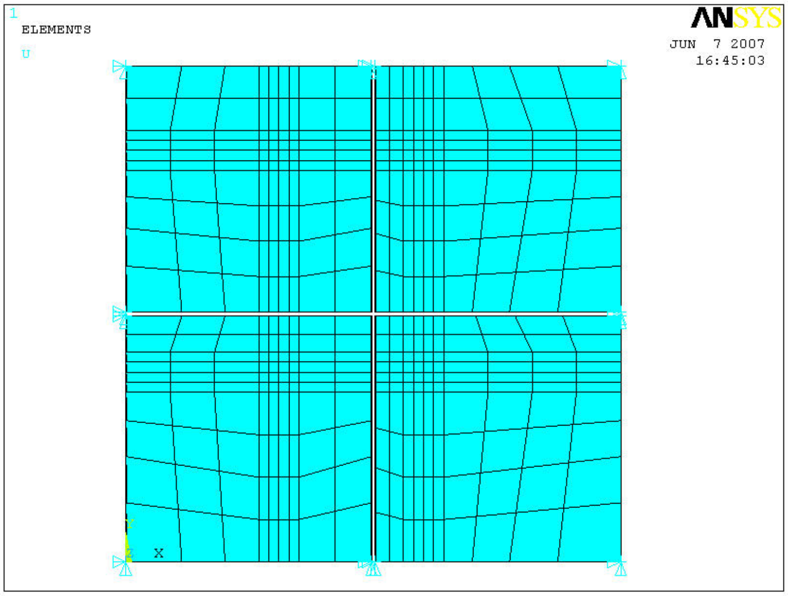


The results for the first mode were:

NODE	UX	UY	UZ	USUM
174	-0.70957E-04	-0.83481E-04	0.73282E-03	0.74096E-03
330	0.61409E-01	-0.27995E-01	0.16824E-01	0.69554E-01
565	0.13529	-0.42635E-01	0.16829E-01	0.14284

So we can see that the movement at the foot should be three orders of magnitude smaller than that at the middle ring.

3.2 Block fixed at three corner points



It is likely that in practice the steel blocks are supported at three points, and the three points I used above are widely-separated. It is therefore surprising to see such a large effect on the first mode. I note that supporting at single points as I have done there is perhaps pessimistic in terms of the support stiffness – on the other hand the floor on which the blocks are resting is not infinitely stiff, so these two effects will cancel out to some extent.

Frequencies:

```
   SET   TIME/FREQ
     1  80.322         cantilever, mostly in X, not much block movement
     2  111.46         cantilever in X, and top surface of blocks moving in Z
     3  121.91         cantilever in Y, blocks moving.
     4  127.13         One block moving, structure not moving much
     5  137.82
     6  144.07
     7  187.27
```

Note that the first frequency has dropped 10 Hz.

Results at the three leg nodes, mode 1:

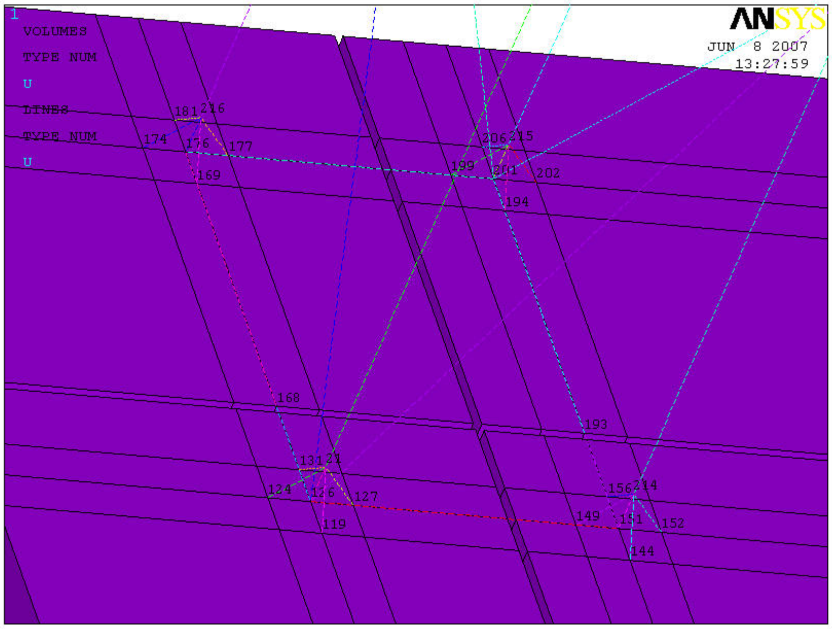
```
  THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN THE GLOBAL COORDINATE SYSTEM

    NODE       UX          UY          UZ          USUM
     174 -0.27769E-02 0.15187E-02 0.24795E-02 0.40207E-02
     330  0.56097E-01-0.26329E-01 0.15835E-01 0.63959E-01
     565  0.12681    -0.40565E-01 0.15843E-01 0.13408
```

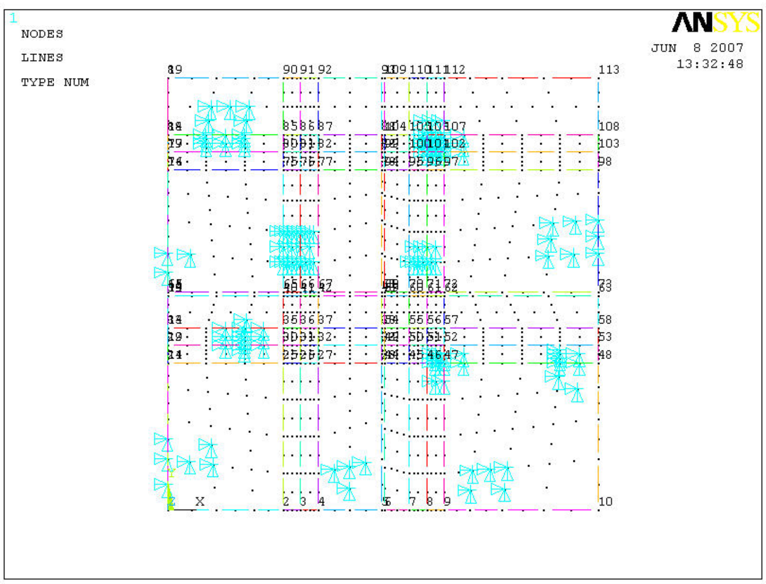
Note that the movements at the foot (node 174), even in this mode with little motion of the blocks in the mode shape, is only about a factor 20 smaller than the motion at the middle ring.

3.3 More realistic support

For this run I included the bars in the bottom ring, modelling them with 50*50 solid cross section. To address the fact that they are clamped to the blocks along their length, but without too much additional modelling work, I fixed them to the bocks at the point where they cross the edge – see diagram and see macro in appendix 1.



I then chose some more “realistic” constraints, shown on this plot of the constrained nodes on the lower surface of the blocks viewed from



above:

The frequencies were

```
  *****  INDEX OF DATA SETS ON RESULTS FILE  *****
```

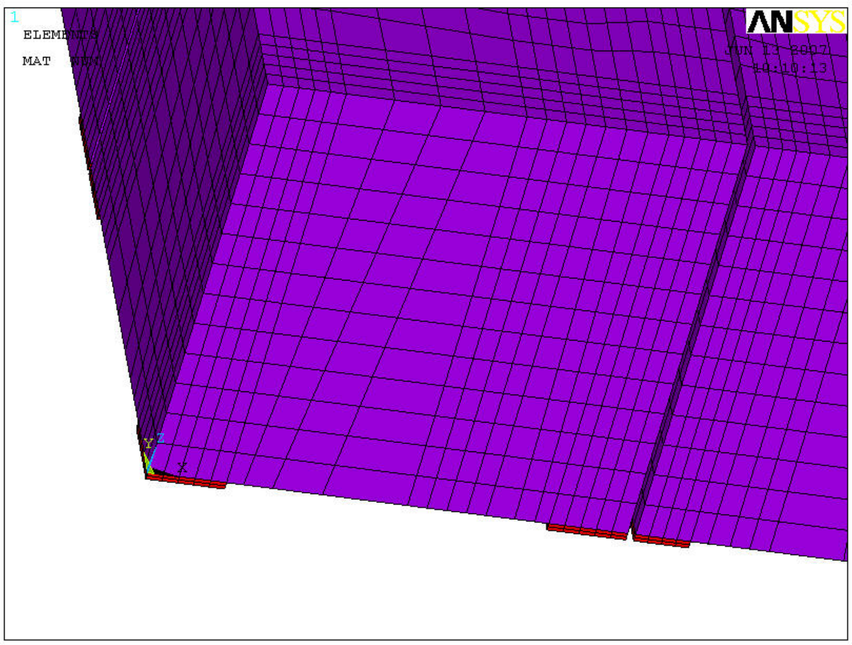
```
SET    TIME/FREQ     LOAD STEP    SUBSTEP   CUMULATIVE
  1   89.324             1          1          1
  2   138.41             1          2          2
  3   195.35             1          3          3
```

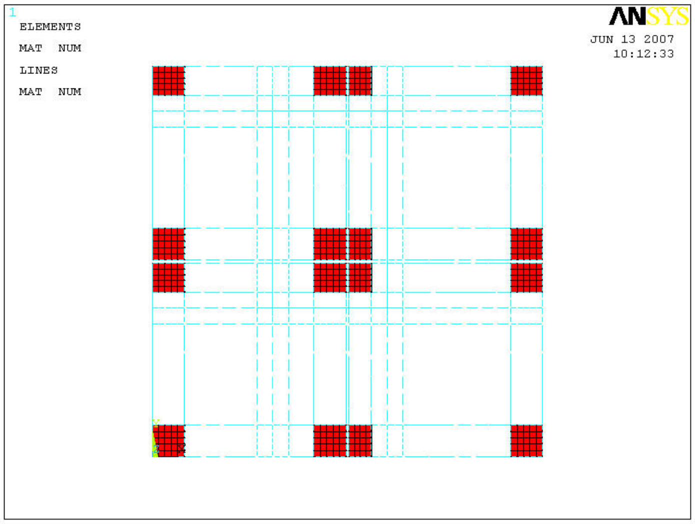
Which are basically the same as with the blocks fixed completely.

It seems we need to untangle the question of just how stiff the floor is. One interesting data point as that a block on its own was found to have a “roll” mode of about 15 Hz.

4. MODEL WITH SOFT PADS SUPPORTING THE BLOCKS

The idea here is to put pads of a soft material under the blocks – the underneath of the pads is constrained, and by varying the modulus of the pads we can vary the amount of constraint on the blocks. See macro in appendix 2, and diagrams below. The location and dimensions of the pads are rather arbitrary; I chose them to minimise the additional model features required. The square pads at the outside corners are 100mm on a side, and they are all 10 mm thick.





The model has ~23000 elements.

4.1 Initial results – pad modulus 5GPa

With the modulus of the pads set to 5 GPa, the modes were

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	86.519	1	1	1
2	141.92	1	2	2
3	185.35	1	3	3

These are similar to the fully-constrained case.

Three nodes along one leg are 168, 255 and 485:

NODE	X	Y	Z	THXY	THYZ	THZX
168	0.38000	1.0900	0.61000	0.00	0.00	0.00
255	0.38000	1.0900	1.4100	0.00	0.00	0.00
485	0.38000	1.0900	2.2100	0.00	0.00	0.00

Movements in the first mode are

NODE	UX	UY	UZ	USUM
168	0.20489E-03	-0.25767E-03	0.10113E-02	0.10635E-02
255	0.60332E-01	0.22101E-01	0.57005E-02	0.64505E-01
485	0.13469	0.32141E-01	0.10227E-01	0.13885

So the movement at the foot is about a factor 30 smaller than that at the middle ring.

4.2 Pad modulus = 45 MPa

To get a frequency in the right range for the blocks, set the modulus of the pads so that the first "bounce" mode of a block is around 50 Hz (cf 15 Hz measured roll mode).

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

$$k = (2\pi f)^2 m$$

So desired k = 180 E6 N/m

$$k = \frac{aE}{l}$$

$$E = \frac{kl}{a}$$

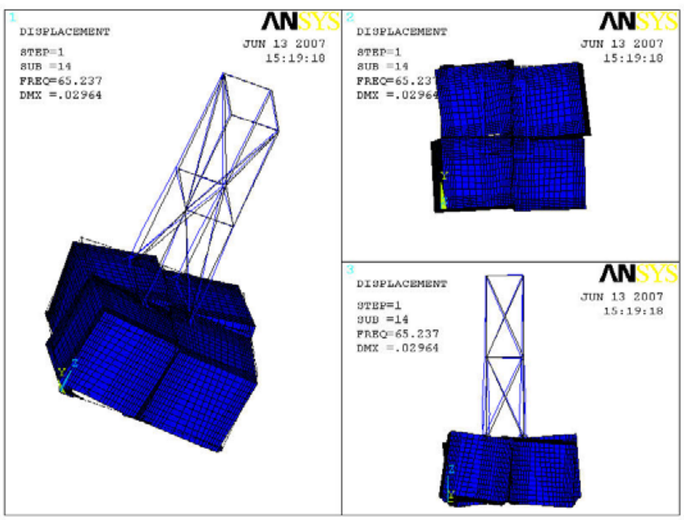
E = 180E6*0.01/(0.1*0.1*4) = 45E6 Pa. Since the pads are not meant to be real rubber, simply a device to allow us to simulate an unknown degree of constraint of the blocks, we are free to set the modulus to any value (subject to stability of the solver).

MPTEMP,1,0
MPDATA,EX,3,,45E6
MPDATA,PRXY,3,,0.3
MPDATA,DENS,3,,2.0e3

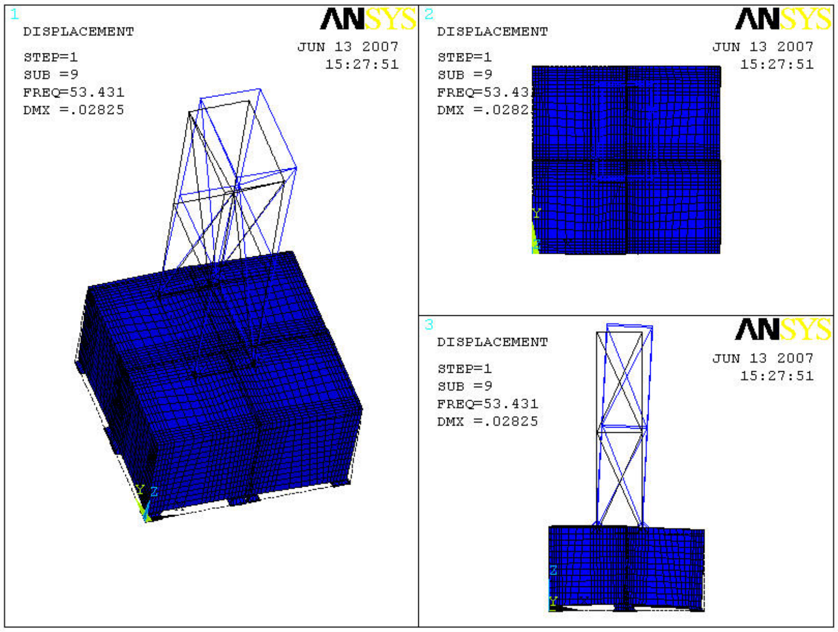
This looks more like it:

```
 SET   TIME/FREQ
   1  24.315     Pads shear in X
   2  24.722     Pads shear in Y
   3  30.718     Blocks yaw en masse on pads about Z
   4  39.149     two blocks yaw out of phase on pads
   5  43.789     two blocks yaw on pads, structure cantilevers in X
   6  44.304     two blocks yaw one way en masse; two the other way
   7  44.580     similar to mode 5
   8  51.809     structure cantilevers in Y
   9  53.431     two blocks lift (stretching pads in Z); structure cantilevers in X
  10  56.862     two blocks roll (about Y) in opposition
  11  58.670     blocks pitch and/or roll
  12  60.153     blocks pitch and/or roll
  13  62.954     blocks pitch, roll and yaw
  14  65.237     blocks pitch, roll and yaw (see diagram below)
  15  72.035     blocks roll about Y, structure cantilevers in X
  16  83.259     two blocks yaw in opposition
  17  87.424     blocks pitch; structure cantilevers in X
  18  101.58     blocks roll; structure goes in torsion
  19  103.19     blocks pitch, structure cantilever in Y
  20  125.84     block roll, structure cantilevers in X
```

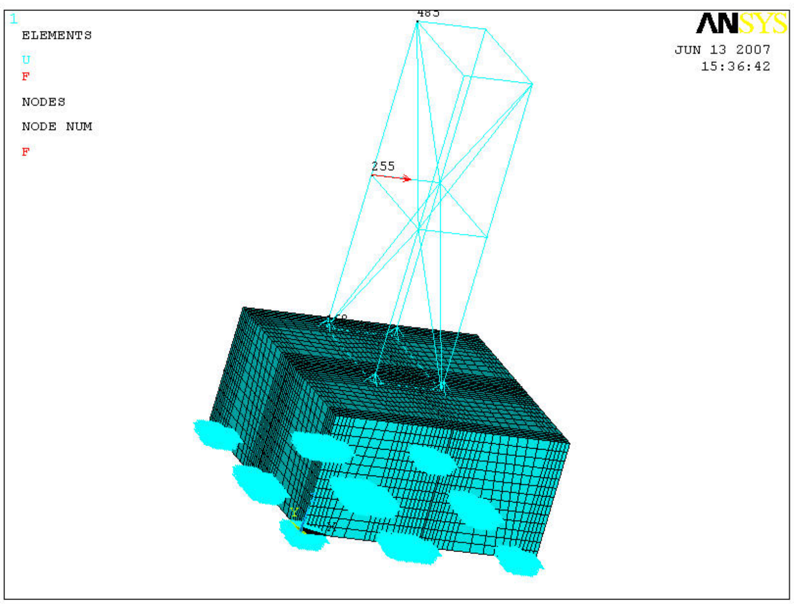
Here is mode 14 – a mode with little movement of the structure



Here is mode 9 in which the structure moves:

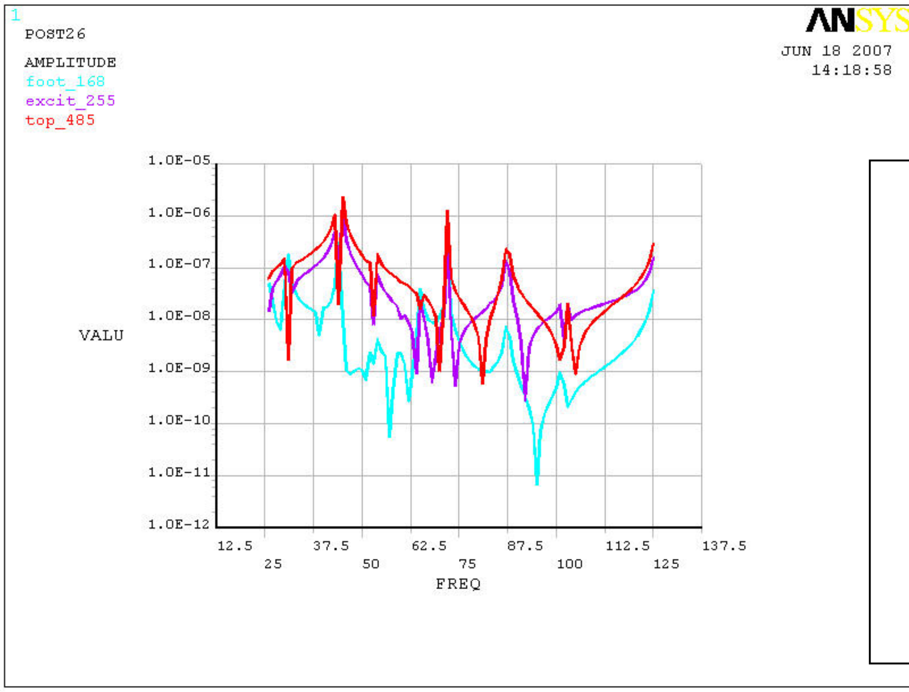


So what happens if we subject this structure to an excitation part-way up the structure?
I applied a force to node 255 (half way up the structure), and ran a full harmonic analysis from 25 to 125 Hz.

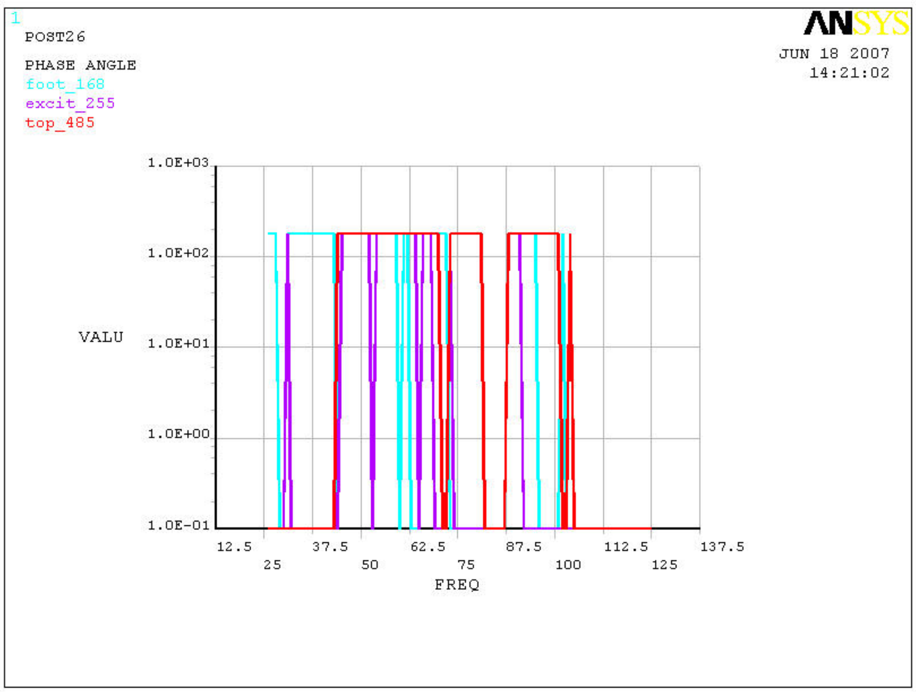


This will take a while…

(weekend run)…



1	24.315	
2	24.722	
3	30.718	
4	39.149	
5	43.789	*
6	44.304	
7	44.580	*
8	51.809	
9	53.431	*
10	56.862	
11	58.670	
12	60.153	
13	62.954	
14	65.237	
15	72.035	*
16	83.259	
17	87.424	*
18	101.58	
19	103.19	
20	125.84	*



Qualitatively, I see peaks at varying heights

Appendix – macro for section 3.3

```
FINISH  ! Make sure we are at
BEGIN level
/CLEAR
*abbr,doit,doit
*abbr,jreplo,/replot
/PREP7

! to build a simple beam model on
steel blocks
!
!Element types
!*
ET,1,BEAM4
!*
ET,2,SOLID186
!*

!For the beams 1 = hollow; 2 = solid
!
R,1,0.0009,3.08E-07,3.08E-
07,0.025,0.025
R,2,0.0025,5.21E-07,5.21E-
07,0.025,0.025


!materials 1 = aluminium; 2 = steel
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,1,,70E9*4
MPDATA,PRXY,1,,0.3
MPDATA,DENS,1,,2.7E3*2


MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,2,,210E9
MPDATA,PRXY,2,,0.3
MPDATA,DENS,2,,7.8E3

! geometry

xoff = 0.23
yoff = 0.14
xstruct = 0.36
ystruct = 0.55
bsize = 0.610
bsizev = 0.610
gap = 0.010
zstruct1 = 0.8
zstruct2 = 1.6
fixoff = 0.05

X0 = 0
X1 = bsize - xoff
x2 = bsize
x3 = x2 + gap
x4 = x1 + xstruct
x5 = x3 + bsize
x6 = x1 - fixoff
x7 = x1 + fixoff
x8 = x4 - fixoff
x9 = x4 + fixoff

y0 = 0
y1 = bsize - yoff
y2 = bsize
y3 = y2 + gap
y4 = y1 + ystruct
y5 = y3 + bsize
y6 = y1 - fixoff
y7 = y1 + fixoff
y8 = y4 - fixoff
y9 = y4 + fixoff
z0 = 0
z1 = bsizev
z2 = z1 + zstruct1
z3 = z1 + zstruct2

!
keypoints

k, 1, x0,y0,z0
k, 2, x6,y0,z0
k, 3, x1,y0,z0
k, 4, x7,y0,z0
k, 5, x2,y0,z0
k, 6, x3,y0,z0
k, 7, x8,y0,z0
k, 8, x4,y0,z0
k, 9, x9,y0,z0
k,10, x5,y0,z0

!lines 1 to 4

l,1,2
,2,3
,3,4
,4,5
!lines 5 to 8
l,6,7
,7,8
,8,9
,9,10

k,11,x0,y6,z0
k,12,x0,y1,z0
k,13,x0,y7,z0
k,14,x0,y2,z0
k,15,x0,y3,z0
k,16,x0,y8,z0
k,17,x0,y4,z0
k,18,x0,y9,z0
k,19,x0,y5,z0

!lines 9 to 12
l,1,11
,11,12
,12,13
,13,14

!lines 13 to 16
l,15,16
,16,17
,17,18
,18,19

!z dimension
k,20,x0,y0,z1
k,21,x1,y1,z1+fixoff
k,22,x1,y1,z2
k,23,x1,y1,z3

!line 17
l,1,20

adrag,1,2,3,4,,,9,10,11,12
adrag,5,6,7,8,,,9,10,11,12

FLST,3,8,4,ORDE,8
FITEM,3,45
FITEM,3,48
FITEM,3,50
FITEM,3,52
FITEM,3,81
FITEM,3,84
FITEM,3,86
FITEM,3,88
LGEN,2,P51X, , , ,gap, , ,0

adrag,90,91,92,93,,,13,14,15,16
adrag,94,95,96,97,,,13,14,15,16

vdrag,all,,,,,,17

/VIEW,  1, -0.236620128544    , -
0.782474382372    ,
0.575972877572
/ANG,   1,   10.5782042749
/REPLO

!restart line numbering from 500
NUMSTR,LINE,500,

!line 500 - 502
l,126,21
,21,22
,22,23

!vertical legs
ldrag,151,201,176,,,,500,501,502

!middle ring
l,22,219
,219,218
,218,217
,217,22

! diagonals
l,126,219
,219,201
,201,217
,217,126

l,23,219
,219,221
,221,217
,217,23

!top ring lines 524-527
l,23,222
,222,221
,221,220
,220,23

!bottom ring lines 528 - 533
l,176,201
,201,193
,193,151
,151,126
,126,168
,168,176

!fixings
l,21,124
,21,131
,21,119
,21,127

,214,156
,214,152
,214,144
,214,149

,215,202
,215,206
,215,194
,215,199

,216,177
,216,169
,216,181
```

```
,216,174

!top ring lines

!meshing
!set element size
lsel,s,line,,500,600
lesize,all,0.01

! structure except top & bottom ring
lsel,u,line,,524,533

mat, 1
real,1
type,1


lmesh,all

!top & bottom ring
lsel,s,line,,524,533
real,2
lmesh,all


!volumes
allsel
mat,2
type,2

vmesh,all

*go, :nofix
!constraints
!fix points on the ground
kpsel,s,loc,z,-0.01,0.01
kpsel,u,kp,,11,19
dk,all,ux,0
,all,uy,0
,all,uz,0

! fix leg ends
ksel,s,kp,,126
,a,kp,,176
,a,kp,,201
,a,kp,,151

dk,all,ux,0
,all,uy,0
,all,uz,0
:nofix

allsel

dk,219,UX,1

sbctra



:end
```

Appendix 2 – macro with pads under the blocks

```
FINISH  ! Make sure we are at
BEGIN level
/CLEAR
*abbr,doit,doit
*abbr,jreplo,/replot
/PREP7

! to build a simple beam model on
steel blocks
! modified to include support pads
12 jun 07
!Element types
!*
ET,1,BEAM4
!*
ET,2,SOLID186
!*

!For the beams 1 = hollow; 2 = solid
!
R,1,0.0009,3.08E-07,3.08E-
07,0.025,0.025
R,2,0.0025,5.21E-07,5.21E-
07,0.025,0.025


!materials 1 = aluminium; 2 = steel;
3 = rubbery stuff
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,1,,70E9*4
MPDATA,PRXY,1,,0.3
MPDATA,DENS,1,,2.7E3*2



MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,2,,210E9
MPDATA,PRXY,2,,0.3
MPDATA,DENS,2,,7.8E3



MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,3,,5e9
MPDATA,PRXY,3,,0.3
MPDATA,DENS,3,,2.0e3

! geometry

xoff = 0.23
yoff = 0.14
xstruct = 0.36
ystruct = 0.55
bsize = 0.610
bsizev = 0.610
gap = 0.010
zstruct1 = 0.8
zstruct2 = 1.6
fixoff = 0.05
xpad = 0.1
ypad = 0.1
zpad = 0.01

x1 = 0
x2 = xpad
x4 = bsize - xoff
x3 = x4-fixoff
x5 = x4+fixoff
x6 = bsize - xpad
x7 = bsize
x8 = x7 + gap
x10 = x4 + xstruct
x9 = x10 - fixoff
x11 = x10 + fixoff
x13 = x8 + bsize
x12 = x13-xpad

y1 = 0
y14 = ypad
y16 = bsize - yoff
y15 = y16-fixoff
y17 = y16 + fixoff
y18 = bsize
y19 = y18 + gap
y20 = y19 + ypad
y22 = y16 + ystruct
y21 = y22 - fixoff
y23 = y22 + fixoff
y25 = y19 + bsize
y24 = y25 - ypad

z0 = 0
z1 = bsize
z2 = z1 + zstruct1
z3 = z1 + zstruct2
z4 = -zpad

!
keypoints

k, 1, x1,y1,z0
k, 2, x2,y1,z0
k, 3, x3,y1,z0
k, 4, x4,y1,z0
k, 5, x5,y1,z0
k, 6, x6,y1,z0
k, 7, x7,y1,z0
k, 8, x8,y1,z0
k, 9, x9,y1,z0
k,10, x10,y1,z0
k,11, x11,y1,z0
k,12, x12,y1,z0
k,13, x13,y1,z0


!lines 1 to 6

l,1,2
,2,3
,3,4
,4,5
,5,6
,6,7
!lines 7 to 11
l,8,9
,9,10
,10,11
,11,12
,12,13

k,14,x1,y14,z0
k,15,x1,y15,z0
k,16,x1,y16,z0
k,17,x1,y17,z0
k,18,x1,y18,z0
k,19,x1,y19,z0
k,20,x1,y20,z0
k,21,x1,y21,z0
k,22,x1,y22,z0
k,23,x1,y23,z0
k,24,x1,y24,z0
k,25,x1,y25,z0

!lines 12 to 16
l,1,14
,14,15
,15,16
,16,17
,17,18
!lines 17 to 22
l,19,20
,20,21
,21,22
,22,23
,23,24
,24,25

!z dimension
k,26,x1,y1,z1
k,27,x4,y16,z1+fixoff
k,28,x4,y16,z2
k,29,x4,y16,z3
k,30,x1,y1,z4

!lines 23 and 24 for vdrags
l,1,26
l,1,30

adrag,1,2,3,4,5,6,12,13,14,15,16
adrag,7,8,9,10,11,,12,13,14,15,16


lsel,s,loc,y,bsize-0.001,bsize+0.001
lgen,2,all,,,,gap
allsel

adrag,145,146,147,148,149,150,12,
13,14,15,16
adrag,151,152,153,154,155,
,12,13,14,15,16

vdrag,all,,,,,23

!select corner areas
FLST,5,16,5,ORDE,16
FITEM,5,1
FITEM,5,6
FITEM,5,25
FITEM,5,30
FITEM,5,-31
FITEM,5,35
FITEM,5,51
FITEM,5,55
FITEM,5,-56
FITEM,5,61
FITEM,5,80
FITEM,5,85
FITEM,5,-86
FITEM,5,90
FITEM,5,106
FITEM,5,110
ASEL,S, , ,P51X

vdrag,all,,,,,24

allsel
/VIEW,  1, -0.236620128544    , -
0.782474382372    ,
0.575972877572
/ANG,   1,   10.5782042749
vplot


!restart line numbering from 1500
NUMSTR,LINE,1500,

!line 1500 - 1502
l,198,27
,27,28
,28,29
```

```
!vertical legs
ldrag,236,276,314,,,,1500,1501,150
2


!middle ring
l,28,397
,397,399
,399,398
,398,28

! diagonals
l,276,28
,28,401
,401,399
,399,276

l,236,28
,28,400
,400,399
,399,236

!top ring lines 1524-1527
l,29,400
,400,402
,402,401
,401,29

!bottom ring lines 1528 - 1533
l,198,258
,258,276
,276,314
,314,298
,298,236
,236,198

!fixings
l,27,199
,27,191
,27,197
,27,205

,394,237
,394,230
,394,234
,394,242

,395,269
,395,275
,395,277
,395,283

,396,308
,396,312
,396,315
,396,320

!meshing
!set element size
lsel,s,line,,1500,1600
lesize,all,0.01


! structure except top & bottom ring
lsel,u,line,,1524,1533

mat, 1
real,1
type,1

lmesh,all

!top & bottom ring
lsel,s,line,,1524,1533
real,2
lmesh,all

allsel

!volumes
lsel,u,loc,z,-10,0.001
lsel,u,loc,z,bsize-0.001,10

lesize,all,fixoff
allsel

vsel,s,loc,z,0,z2
mat,2
type,2

vmesh,all

vsel,s,loc,z,-bsize,0
mat,3,type,2
vmesh,all
!*go,:end

!constraints
!fix points on the ground
asel,s,loc,z,-zpad-0.001,-
zpad+0.001
da,all,ux,0
,all,uy,0
,all,uz,0


!*go, :nofix
! fix leg ends
ksel,s,kp,,126
,a,kp,,176
,a,kp,,201
,a,kp,,151

dk,all,ux,0
,all,uy,0
,all,uz,0
:nofix

allsel


sbctra



:end
```