LIGO Laboratory / LIGO Scientific Collaboration

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Finite Element Analysis of Advanced LIGO SUS ETM Structures using ANSYS Classic beam models

Tim Hayler, Mark Barton, Caroline Cantley, Dennis Coyne, Justin Greenhalgh, Russell Jones, M Perreur-Lloyd, Joe O'Dell, Norna Robertson, Janeen Hazel Romie, Ken Strain, Calum Torrie, Ian Wilmut.

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This is an internal working note
of the Advanced LIGO Project, prepared by members of the UK team.

Institute for Gravitational Research
University of Glasgow
University Avenue, Glasgow G12 8QQ,
Scotland UK

+44 (0) 131 440 5880

Department of Physics
University of Birmingham

+44 (0) 121 414 6447

Engineering Department
CCLRC Rutherford Appleton Laboratory
Chilton, Didcot, Oxon OX12 0NA
Phone +44 (0) 1235 44 5297
Fax +44 (0) 1235 445843

Particle Physics and Astronomy Research Council (PPARC)

http://www.ligo.caltech.edu/
http://www.eng-external.rl.ac.uk/advligo/papers_public/ALUK_Homepage.htm.

Introduction

The purpose of this document is to improve the structural performance of the SUS ETM structure by introducing a third structure known as the sleeve design. The existing x-bracing in the lower structure looks does not increase the fundamental frequency, the reason for this is fully explained in T060059-00-K section 6. The sleeve design seeks to take advantage of the four stiff corners of the upper structure, increase the section/stiffness of the "x" braces and reduce the mass of the lower structure. The document looks at trends for single and double cross bracing with varying wall thickness.

Section 1

This section compares a model of the upper structure done in ANSYS workbench with a model of the same structure done in ANSYS Classic. The ANSYS Classic model is made using beam elements; the comparison is done for verification of the beam model.

Table 1. Comparison between the ANSYS workbench and classic analysis of the upper structure.

Mode	Mode shapes Workbench versus classic	ANSYS workbench solution [Hz]	ANSYS beam model solution [Hz]
1st	same	249.3	227.49
2nd	same	250.26	228.79
3rd	dissimilar	270.1	290.74

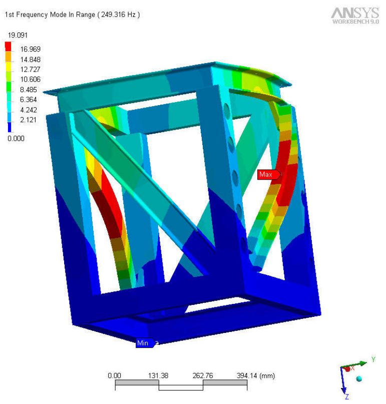


Fig 1. ANSYS Workbench solution of upper structure, 1st mode 249.3Hz

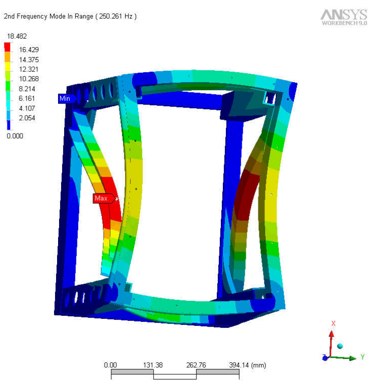


Fig 2. ANSYS Workbench solution of upper structure, 2nd mode 250.26Hz

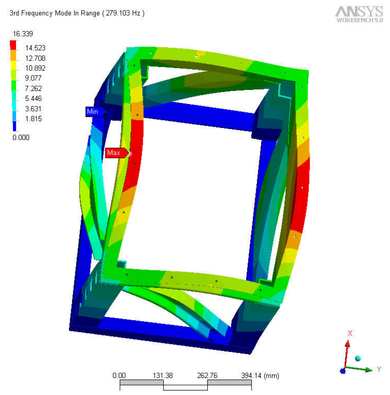


Fig 3. ANSYS Workbench solution of upper structure, 3rd mode 270.1Hz

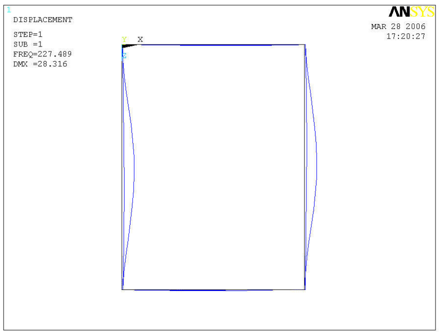


Fig 4. ANSYS classic beam model solution of upper structure, 1st mode 227.49Hz

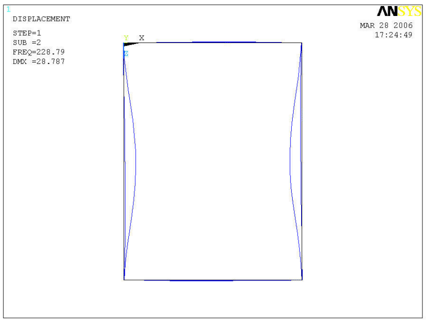


Fig 5. ANSYS classic beam model solution of upper structure, 2nd mode 228.79Hz

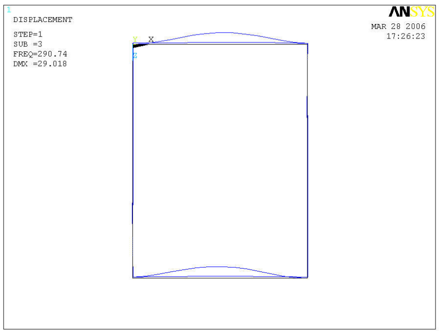


Fig 6. ANSYS classic beam model solution of upper structure, 3rd mode 290.74Hz

Conclusion

The two models compare favourably until the third mode. The discrepancy in the third mode may be attributed to the fact that in the beam model all the neutral axes line up perfectly where as in the workbench model the neutral axes are offset giving rise to new modes.

Section 2

This section takes the upper structure beam model from section one and expands it to include a sleeve design for the lower structure. Models are run to evaluate the cross section of the members, the nature of the cross bracing and the effect of additional mass.

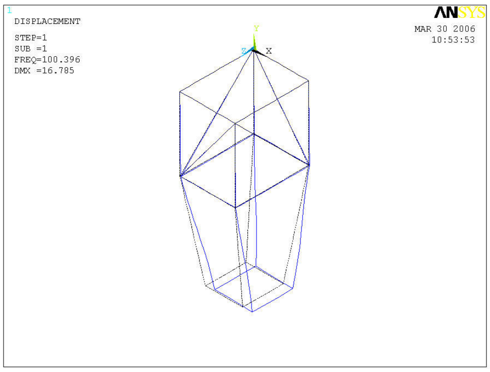


Fig 7. Upper structure and sleeve design with no cross bracing.

Table 2. Size of box section in the sleeve versus frequency, reference fig 7.

Box section with 2mm wall thickness [mm]	First two frequencies [mm]
20 x 20	35,39
30 x 30	54,60
40 x 40	72,80
50 x 50	87,97
60 x 60	100,112

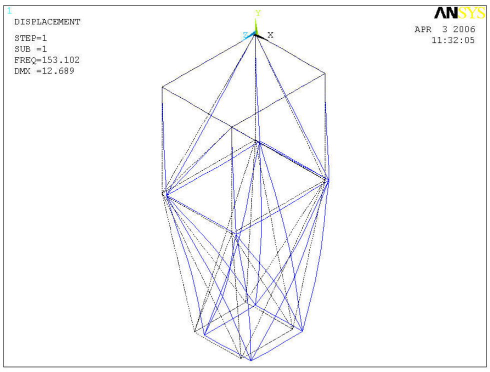


Fig 8. Upper structure and sleeve design with double cross bracing.

Table 3. Size of box section in the sleeve design versus frequency for double cross bracing, reference fig 8.

Box section with 2mm wall thickness [mm]	First two frequencies [mm]
20 x 20	113,115
30 x 30	148,162
40 x 40	153,179
50 x 50	149,180
60 x 60	143,175

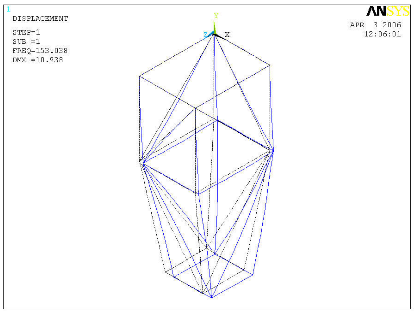
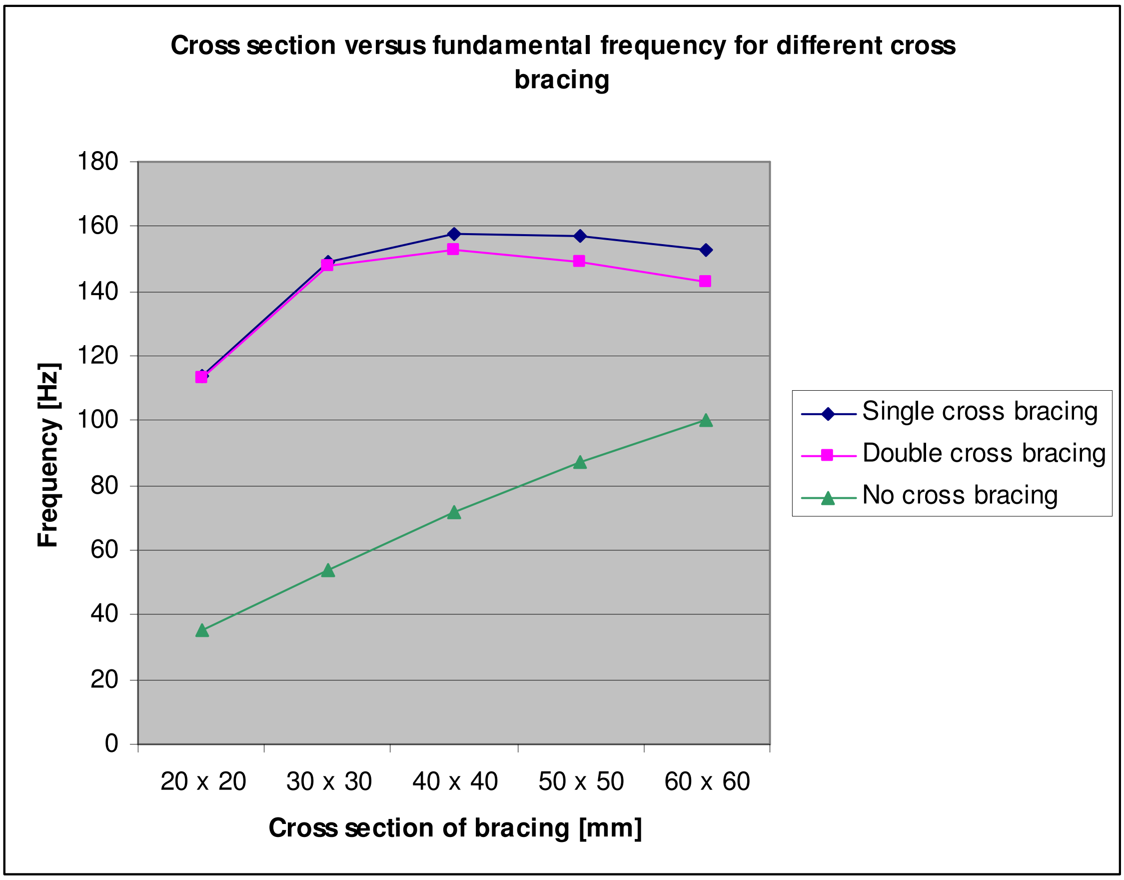


Fig 9. Upper structure and sleeve design with single cross bracing.

Table 4. Size of box section in the sleeve design versus frequency for single cross bracing, reference fig 9.

Box section with 2mm wall thickness [mm]	First two frequencies [Hz]
20 x 20	114,115
30 x 30	149,163
40 x 40	158,181
50 x 50	157,183
60 x 60	153,179

Fig 10. Graph of the lower structure design showing increasing cross section of members with 2mm wall thickness versus fundamental frequency for different cross bracing.



Graph shows that a single cross braced structure gives the best frequency.

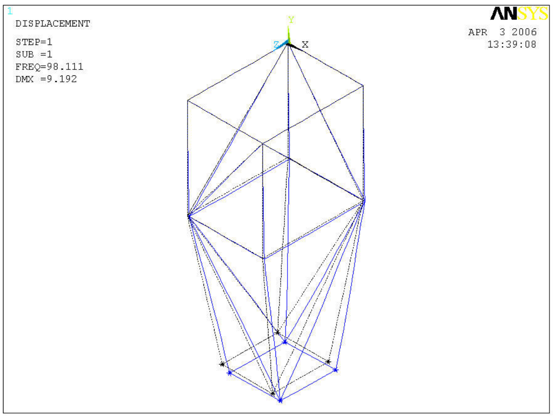


Fig 11. Upper structure and sleeve design with single cross bracing and additional mass of 2kg on each corner, making total additional mass 8kg.

Table 5. Size of box section in sleeve design versus frequency for single cross bracing with and without additional mass of 2kg on each corner, making total additional mass 8kg, reference fig 11.

Box section with 2mm wall thickness [mm]	First two frequencies [Hz]	First two frequencies with additional 8kg [Hz]
20 x 20	114,115	77,91
30 x 30	149,163	89,121
40 x 40	158,181	98,127
50 x 50	157,182	103,129
60 x 60	153,179	106,131

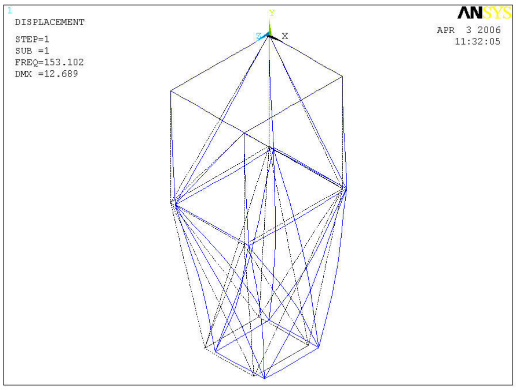


Fig 12. Upper structure and sleeve design with double cross bracing and additional mass of 2kg on each corner, making total additional mass 8kg.

Table 6. Size of box section in sleeve design versus frequency for double cross bracing with and without additional mass of 2kg on each corner, making total additional mass 8kg, reference fig 12.

Box section with 2mm wall thickness [mm]	First two frequencies [Hz]	First two frequencies with additional 8kg [Hz]
20 x 20	113,115	101,102
30 x 30	148,162	112,137
40 x 40	153,179	115,143
50 x 50	149,180	114,144
60 x 60	143,175	113,142

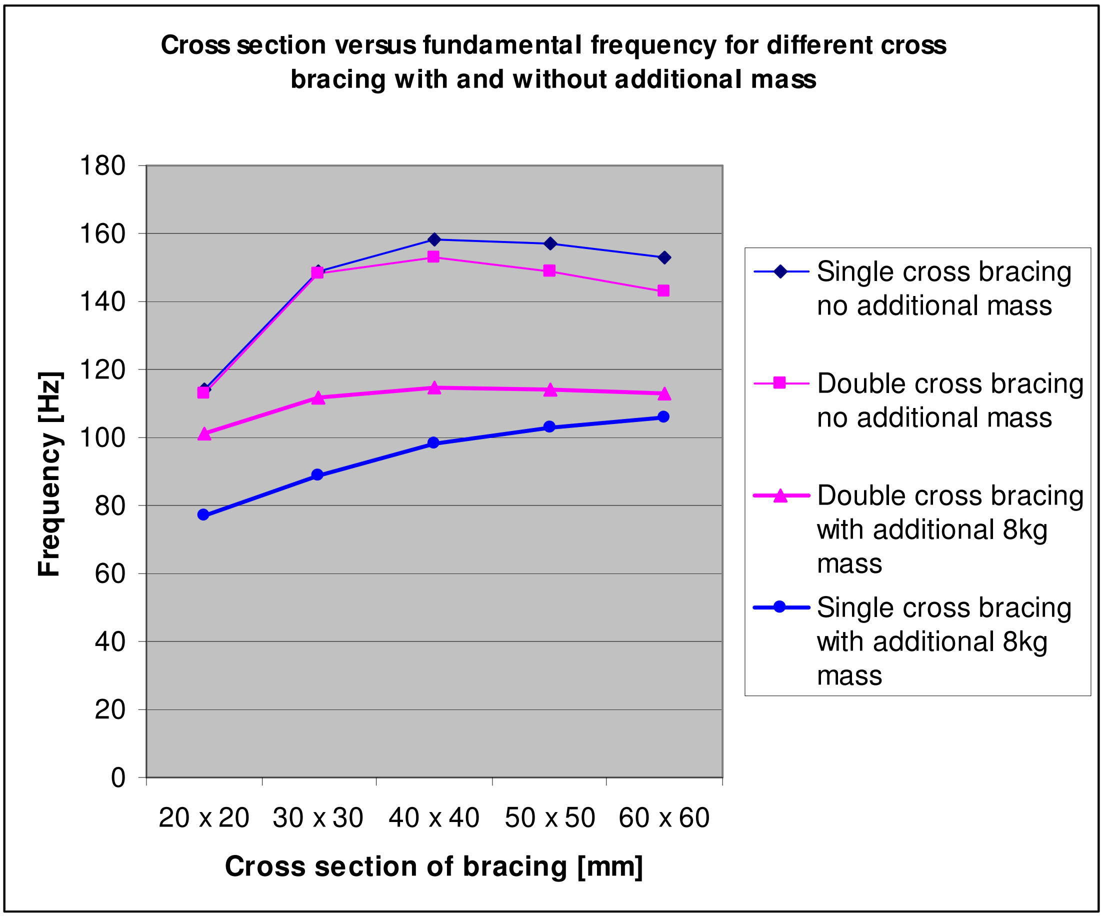


Fig 13. Graph of the sleeve design showing different cross section of members with 2mm wall thickness versus fundamental frequency for single and double cross bracing with or without additional 8kg mass.

The graph shows the relationship between mass and stiffness, it demonstrates the point at which adding material to increase the stiffness stops being advantageous.

Table 7. Additional mass versus frequency for double cross bracing 50 x 50 x 2mm section, reference fig 12.

Additional Mass [Kg]	First two frequencies [Hz]
0	149,180
4	129, 160
6	121, 151
8	114, 144
10	108,137
12	103, 131
14	99,125
16	95, 120
18	91,116

Table 8. Additional mass versus frequency for single cross bracing 50 x 50 x 2mm section, reference fig 11.

Additional Mass [Kg]	First two frequencies [Hz]
0	157, 183
4	124, 150
6	112,139
8	103, 130
10	96, 122
12	90, 115
14	85, 110
16	81, 105
18	78, 101

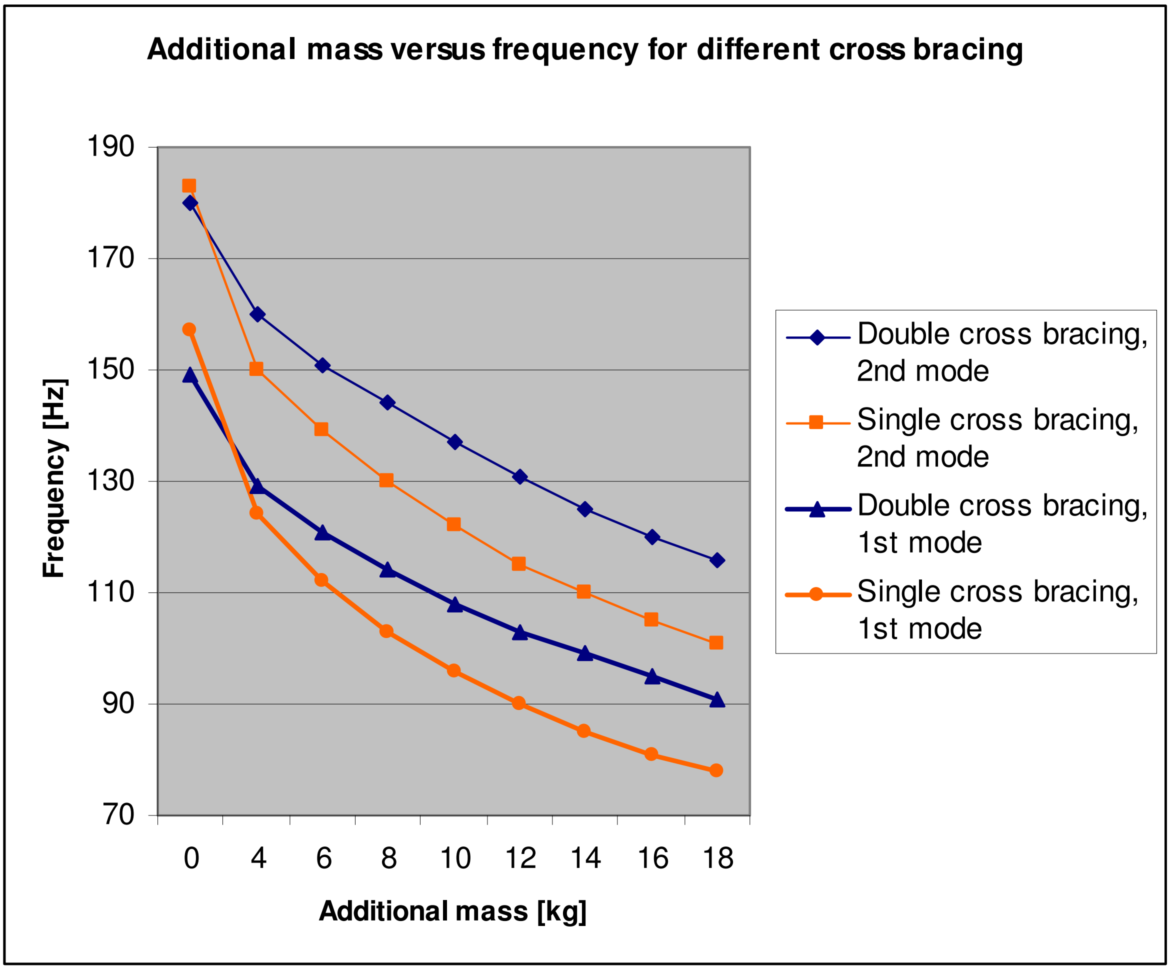


Fig 14. Graph of the sleeve design showing additional mass versus frequency for single and double cross bracing 50 x 50 x 2mm section.

The graph shows the relationship between the inherent mass of the sleeve design and what happens when you add additional mass. With no additional mass single cross bracing gives the best frequency. With 2kg of additional mass both single and double cross bracing gives the same frequency. When adding more then 2kg of additional mass double cross bracing gives a better frequency. Adding additional mass makes the inherent mass of the design have a negligible effect; therefore in this instance double cross bracing is better.

Table 9. Additional mass versus frequency for double cross bracing and different wall thickness.

Additional Mass [kg]	First two frequencies 50 x 50 x 2mm [Hz]	First two frequencies 50 x 50 x 4mm [Hz]	First two frequencies 50 x 50 x 6mm [Hz]
0	149, 180	120, 148	105, 130
4	129, 160	111, 138	99, 124
8	114, 144	103, 129	93, 118
12	103, 131	96, 122	89, 113
16	95, 120	91, 115	85, 108

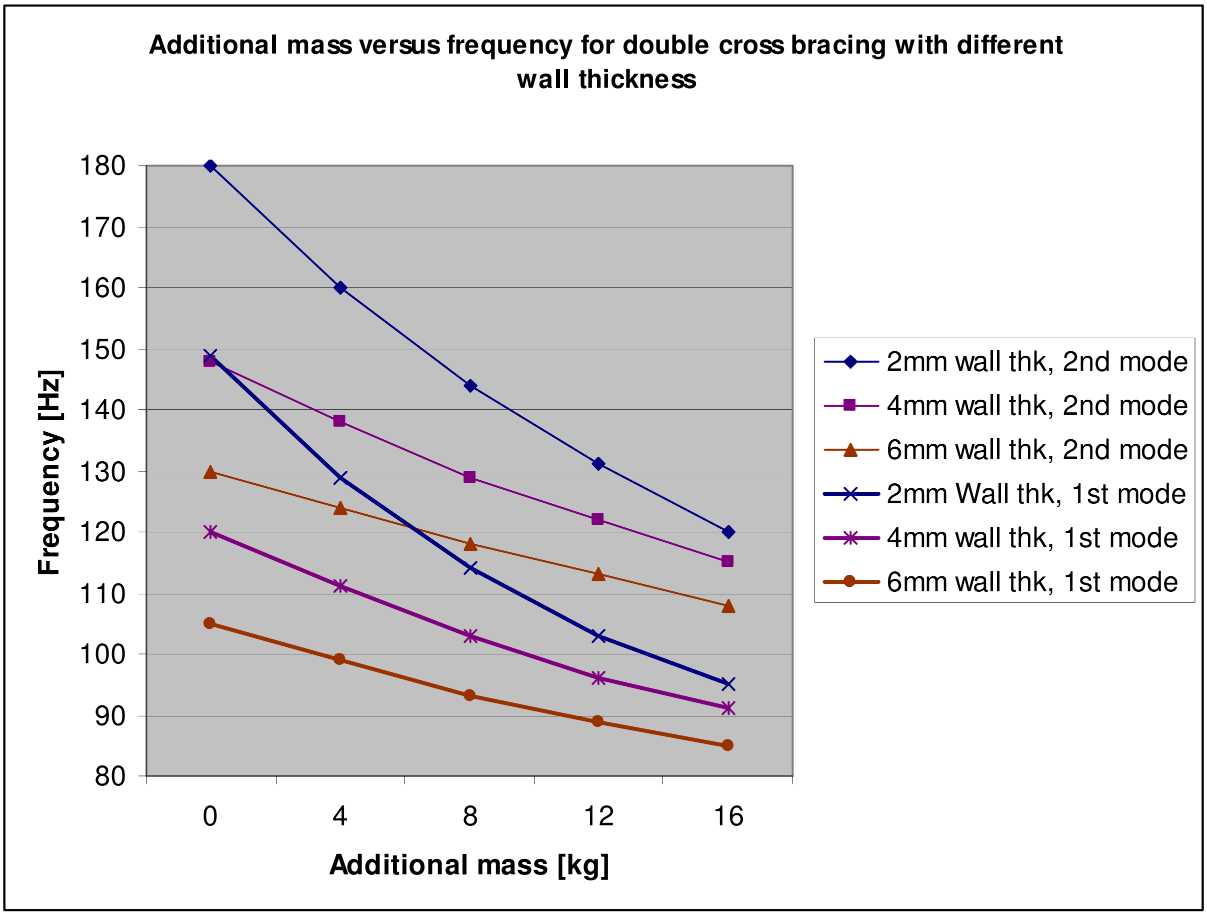


Fig 15. Graph of the sleeve design, additional mass versus frequency for double cross bracing 50 x 50mm section with different wall thickness.

The graph shows the effect of additional mass with respect to total mass of the sleeve design. The more material in the sleeve design the less impact the additional mass has.

Table 10. Additional mass versus frequency for single cross bracing and different wall thickness.

Additional Mass [kg]	First two frequencies 50 x 50 x 2mm [Hz]	First two frequencies 50 x 50 x 4mm [Hz]	First two frequencies 50 x 50 x 6mm [Hz]
0	157, 183	132, 156	117, 140
4	124, 150	116, 139	107, 129
8	103, 130	104, 126	99, 120
12	90, 116	95, 116	92, 112
16	81, 105	88, 108	87, 106

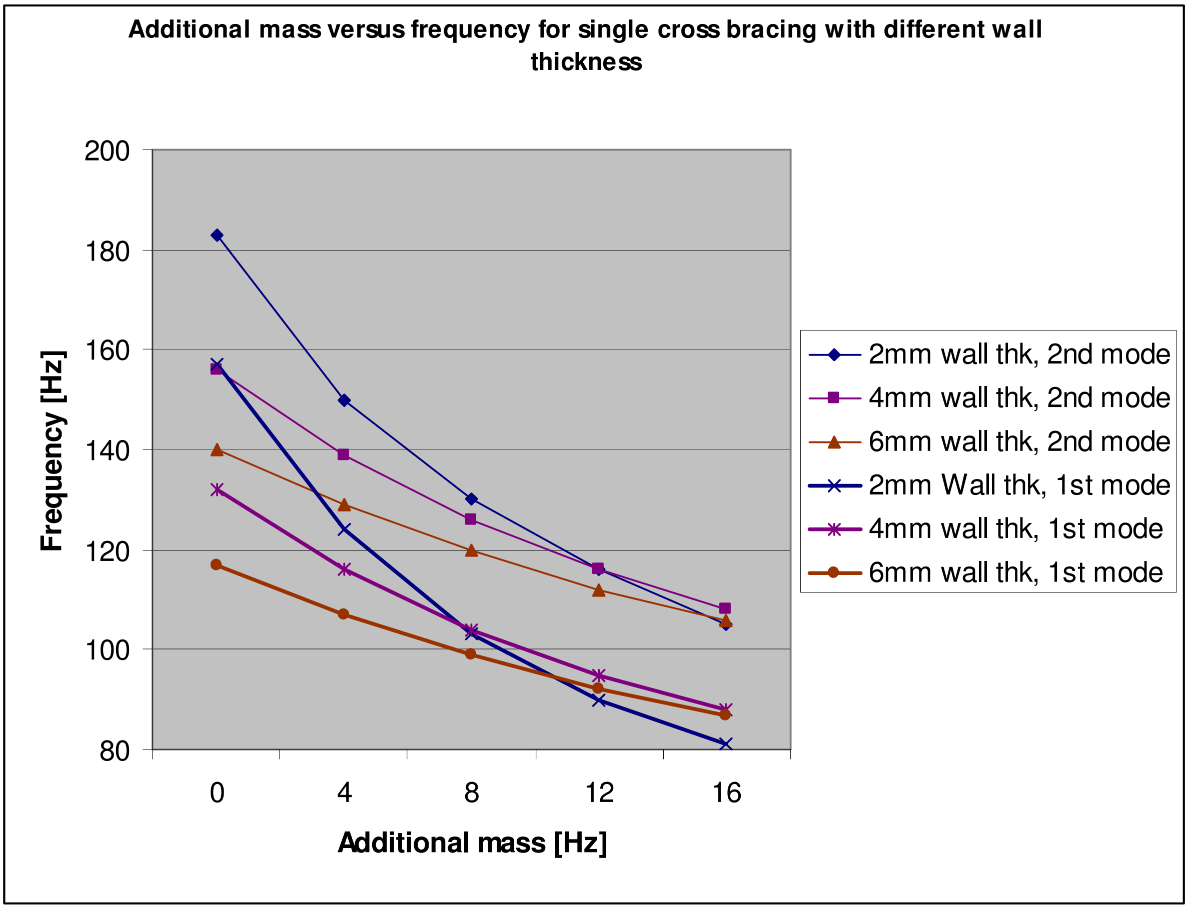


Fig 16. Graph of the sleeve design, additional mass versus frequency for single cross bracing 50 x 50mm section with different wall thickness.

The graph shows the most effective cross section for a given additional mass.

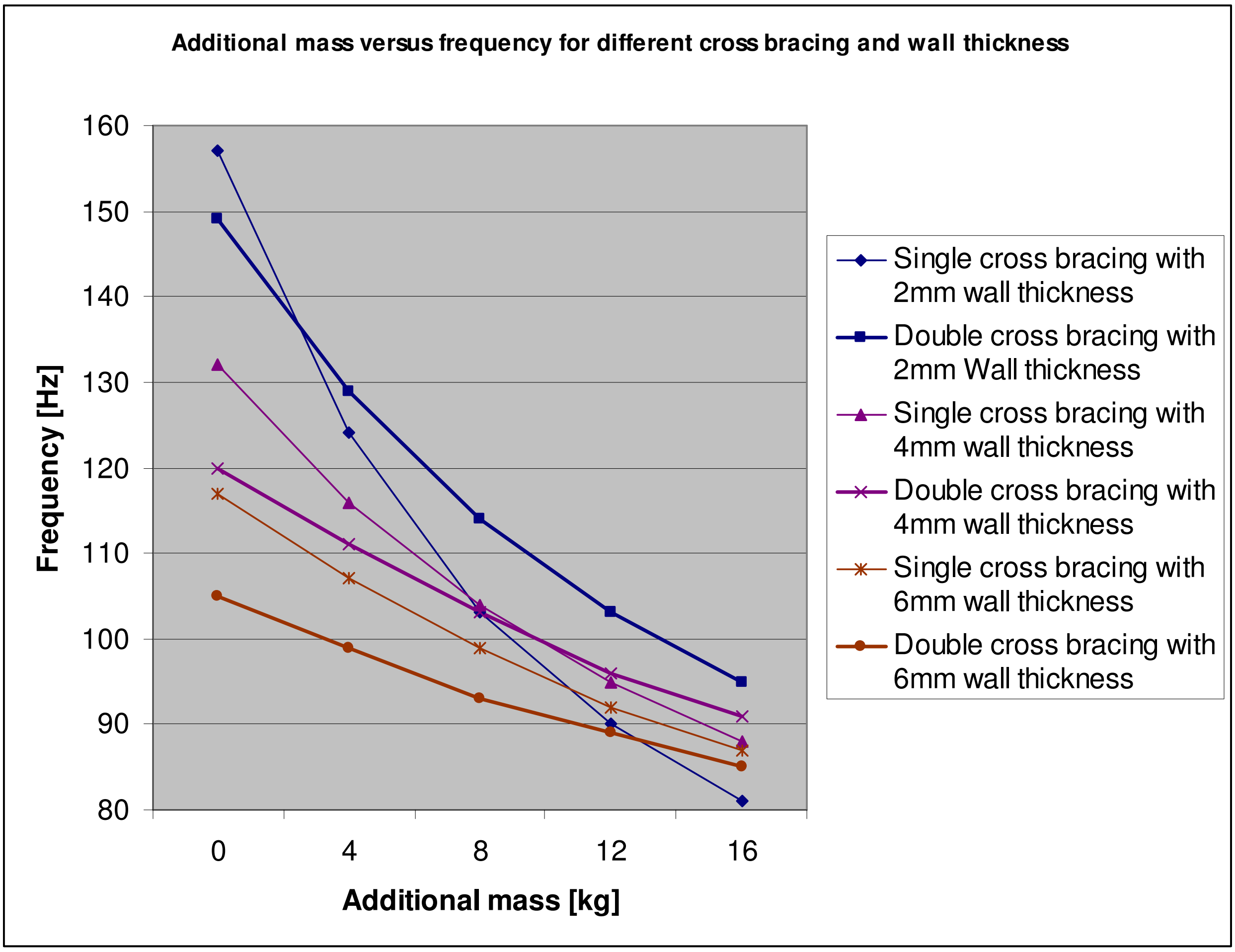


Fig 17. Graph of the sleeve design, additional mass versus fundamental frequency for single and double cross bracing 50 x 50mm section with different wall thickness.

The graph shows the most effective cross section and type of cross bracing for a given additional mass.

Conclusion

It's anticipated that the additional mass in the lower structure from the inner functional part will be in the range of 8 – 12 kg, in this range there is no discernable difference in the frequency between 50 x 50 x 4mm cross section with single or double cross bracing. The recommendation is that 50 x 50 x 4mm cross section with single cross bracing be used, principally for ease of manufacture and uniformity of the upper and lower structures. The fundamental frequency is predicted to be 100Hz +/- 5Hz.