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OPTIMAL LOCATIONS FOR HEAVY LIFTS FOR OFFSHORE PLATFORMS

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Abstract

Lift installation of a major marine or offshore structure necessitates detailed evaluation of inter-dependent engineering and construction constraints that influence the feasibility, safety and cost-effectiveness of the lifting operations. Due to the advancements in heavy lift technology, large modularized ship blocks may be fully outfitted, and then lifted and joined to form the entire ship. Similarly, an offshore structure may be fabricated in a yard, transported to the selected offshore location, and then installed by lifting. The objectives of this paper are to find the locations of optimum positions of offshore platform heavy lift points using the method of evolution strategies either minimizing the moment or maximizing the natural frequency. The results obtained are compared with the published results. The optimal positions of simple supports are located to maximize the fundamental frequency of beam or plate structure taking into account both elastic and rigid supports. The minimum stiffness of a simple support (or point) that raises a natural frequency of a beam to its upper limit is investigated for different boundary conditions. The solution also provides insight into dynamics of a beam with an intermediate support for more general boundary conditions. Finite element approach is used for solving the problems. The computer packages such as PREWIN/FEAST, SAP90 are used for performing finite element analysis.

Keywords: Offshore platform; lift point; evolution strategies; fundamental frequency; support position optimization; prewin/FEAST

1. Introduction

1.1 Introduction to offshore structures

The development of offshore structures for exploration of oil and gas has played an essential role in laying down foundations of the modern world. Oil price rises caused by high oil demand in the 1970's has prompted offshore development throughout the world in order to be self sufficient. Offshore structures can be designed for installation in protected waters,

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such as lakes, rivers, and bays or in the open sea, many kilometers from shorelines. The oil and gas exploration platforms are the best example of offshore structures that can be placed in water depths of 2 kilometers or more. These structures may be made of steel, reinforced concrete or a combination of both. Although some of the older structures were made of reinforced concrete, and even earlier ones were actually made of timber.

Offshore structures may be used for a variety of reasons:

- Oil and gas exploration
- Navigation aid towers
- Bridges and causeways
- Ship loading and unloading facilities

1.2 Types of offshore oil/gas exploration structures

Offshore oil/gas exploration (and drilling) platforms can be of the following types. Converted Jackup barges

a) Onshore platform
b) Fixed platform
c) Jackup rig
d) Semi-submersible
e) Drill ship
f) Tension leg platform

Each of these types shown in Figure 1 is chosen primarily due to water depth considerations, and secondly due to the intended service and quantity of deck equipment necessary to perform its service.

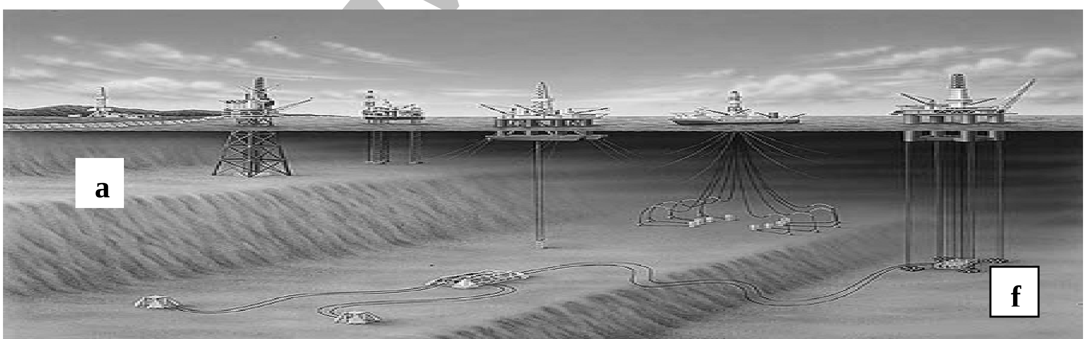

Figure 1. (a) Onshore platform (b) Fixed platform (c) Jackup rig (d) Semi-submersible (e) Drill ship (f) Tension leg platform

1.3 Heavy lift [2]

The objective of a heavy lift operation is to safely lift a module (a generic term for offshore/marine structure or ship block) from the start (pick-up) site and accurately install it at the target (put-down) site. In heavy lift design, as illustrated in Figure 2, the basic input data from sites (start and target sites), module, and crane vessel are consolidated and processed to derive the lift procedure, rigging arrangement and details for rigging components while satisfying the constraints due to structural behavior, geometrical arrangement and other contingency requirements.

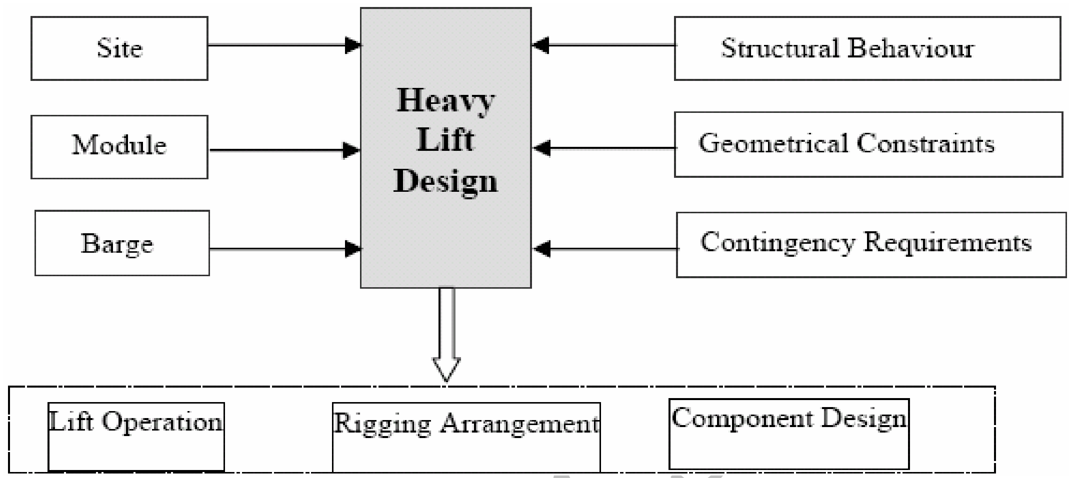

Figure 2. Considerations in heavy lift design

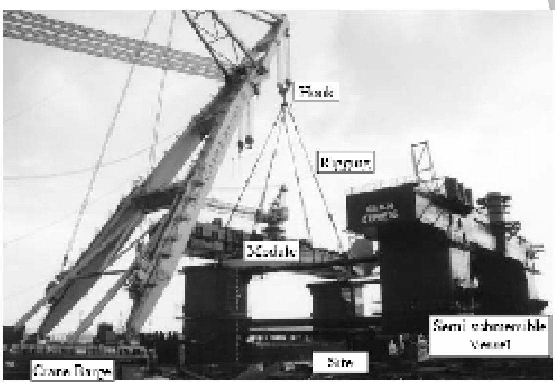

Figure 3. Lift installation of side block using single hook-4 sling rigging arrangement

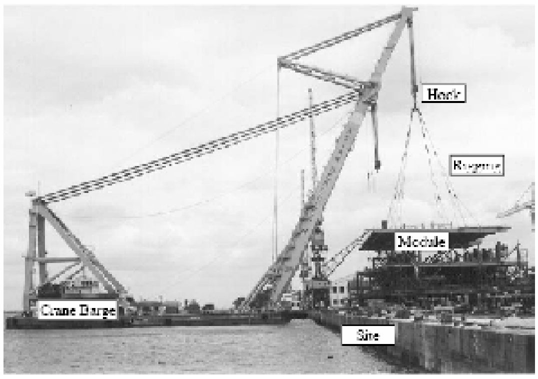

Figure 4. Lift installation using multi-tier rigging system

Offshore hook-up and commissioning costs are very high as compared to those for doing the same work onshore. Thus, it is necessary to focus on the installation phase and to design the structures for ease of construction and installation. This led to the fabrication of very large module on shore in ‘fabrication yards’. They are transported to the offshore assembly site on barges. The start and target sites should be investigated for the necessary barge access and manoeuvring. The water depth at location, geometrical details of the module and other near-by objects, and relevant characteristics at both start and target sites will affect the accessibility, movement and gesture (that is, barge orientation, boom and jib angles) of the crane vessel, and the associated rigging configurations should be considered.

1.4 Lift points [3]

The lift points are generally located at the available strong points in the module to prevent excessive structural deformation or damage during the lifting operation. These lift points should be selected to allow the lifting forces to flow smoothly into the main structural members. In addition, the compatibility of the rigging selected and the associated lift point type (padeye, plate trunnion or pipe trunnion) requires detailed considerations. In certain cases, reinforcement may be required to strengthen the module and to maintain the geometric dimensions to ensure tight tolerances for assembly. Special attention needs to be given to the local deformation and stresses of the lifted module, as well as the assembled blocks during the assembling operations to ensure that contact and impact forces are minimized.

1.5 Rigging design [3]

The rigging arrangement to be selected should consider the available strong points in the module and other installation requirements. A spreader bar or frame, with appropriate rigging arrangement, may be used to prevent physical interference and protect the exposed equipment from damage (as seen in Figures 3-4). A greater sling angle, with respect to the horizontal plane, generally results in proportionally smaller compressive forces acting on the module structure. For the proposed sling angle, the strength and associated capacity of the crane hook prongs needs to be checked. It is recognized that the maximum dimensions of modules are constrained by the crane capacity and reach of the crane barge, and the minimum clearance requirements between the module and the crane boom due to the rapid fall off in the crane capacity with lift radius. Incorrect selection of rigging arrangement may lead to damage of components, structural failure or personal injury and may thus have major implications to the project cost and schedule.

1.6 Padeye, plate trunnion or pipe trunnion [3]

Fabricated trunnions may be used in conjunction with large diameter wire rope slings (or grommets) (see Figure 5) in the lift installation of heavy marine and offshore structures. A fabricated trunnion may have a shear plate slotted through the main body (which may be a plate or a pipe) with two side braces. The fabricated trunnion used in the lift installation of the plated deck structure offered significant advantages over other lift point component types such as pad-eye (see Figure 6) (which is constrained by available shackle with limited capacity) and cast pad-ear (which may require long lead-time). It is appropriate to highlight that the four locations selected for attaching the pipe trunnions to the centre block are the most appropriate locations due to the intersection of the primary transverse and longitudinal bulkheads. If additional lift points were selected, this might have resulted in relative distortion of the deck during lifting and thus would be counterproductive.

Figure 5. Pipe trunnions for side block lift

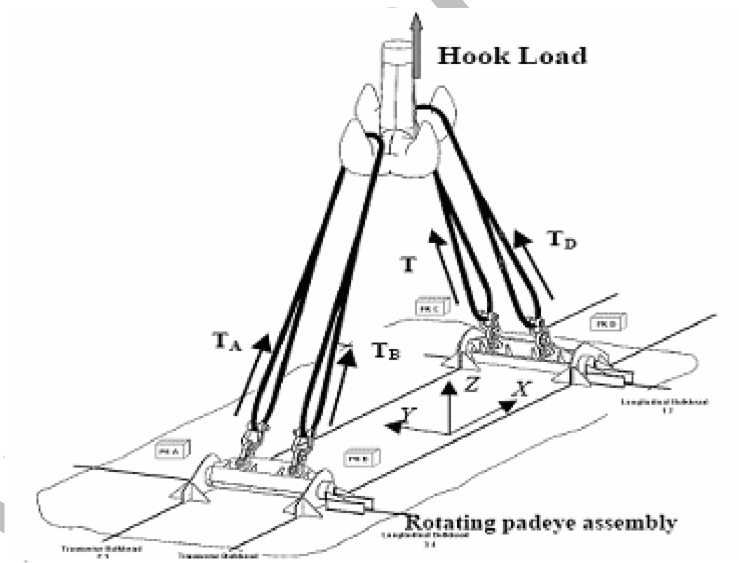

Figure 6. Schematic arrangement of rotating padeye

2. Remarks on the Approaches

2.1 Problem description

Lift installation of a major marine or offshore structure necessitates detailed evaluation of inter-dependent engineering and construction constraints that influence the feasibility, safety and cost-effectiveness of the lifting operations. So many studies were made in this region especially by Choo [2]. In this work, optimal locations of lift points are determined using evolution strategies (Papadrakakis *et al*. [4,5] minimizing the moment or maximizing the frequency.

2.2 Finite element approach

The Finite Element Method of analysis is a very popular tool for computer solution of complex problems in Engineering. This method is very successful because of its generality, the formulation of the problem in variational and weighted residual forms, discretization of the formulation and the solution of resulting finite element equations. Finite element method models a structure as an assembly of elements or components with various forms of connection between them. Thus, a continuous system is modeled as a discrete system with a finite number of elements interconnected at finite number of nodes. The behaviour of individual elements is characterised by the element's stiffness or flexibility relation, which altogether leads to the system's stiffness or flexibility relation.

2.3 Evolution strategies [4], papadrakakis et al. [5]

Evolution strategies were proposed for parameter optimization problems by Rachenberg [8] and Schwefel [9]. Similar to Genetic Algorithms (GA) the (ES) imitates biological evolution in nature and has two characteristics that differ from other conventional optimization algorithms:

(1) In place of the usual deterministic operators, they use randomized operators: mutation, selection and recombination;

(2) Instead of a single design point, they work simultaneously with population of design points in the space of variables.

The second characteristic allows for natural implementation of GAs and ESs in a parallel computer environment. The ESs, however, achieve a higher rate of convergence than GAs owing to their self-adaptation search mechanism and are considered more efficient for solving real world problems. The ESs developed by Rechenberg [8] and Schwefel [9] were commonly applied for continuous optimization problems. In conventional optimization approaches, sensitivity analysis plays a very important role. The reader may refer to the paper by Rajasekaran [7] for more details on Evolution strategies.

4. Choice of Software

4.1 Pre win /FEAST

Interactive graphical pre and post processor for FEAST Package was developed by Vikram Sarabhai Space Research Centrere [1], Thiruvananthapuram. With growing complexity of different space structures, the rapid need for having a reliable structural analysis capability to predict the response of the structure under various operational conditions was solved to its most extent by finite element method. Also, the inherent characteristic of finite element method lends itself for generalization so that various finite elements can be clubbed together in a single computer program package for structural analysis based on finite element method. Ready to run feast data file for finite element models can be created using this software. The static and dynamic analysis can be performed using PREWIN/FEAST which is a general-purpose computer program package for structural analysis based on finite element method. The displacements obtained by static analysis can be used to view the deflected shape of the structure. Dynamic analysis is performed to arrive at the natural frequency.

4.2 SAP90

SAP90-Structural analysis programs is a DOS based software which enables analysis of complex structures with easily understandable input syntaxes. This gives results in three separate output files which help in correcting the errors if any, to check and print the input data in tabulated formats, saving the displacements and reaction results and frame element forces. This package could be combined with Evolution strategies software to perform optimum structural analysis based on finite element method.

4.3 Symbolic processing

Computers can perform symbolic calculations in addition to mere numerical computations for which they are originally designed. Computer algebra (or symbolic-manipulation) systems are essentially “expert systems” incorporating knowledge in the field of mathematics. They possess the remarkable capability of manipulating not only numbers, but also abstract symbols which represent stiffness matrices in the Finite Element Method (FEM). Symbolic processing bypasses time-consuming numerical quadrature operations, especially as the number of Gauss points increases as meshes are refined and the repetitive calculations become necessary. Works were carried out on the symbolic computation in structural engineering by Pavlovic [6]. Mathematica developed by Wolfram [12] is one such recent powerful system in symbolic processing. Some of its features include choosing from hundreds of built-in functions for algebra, calculus, graphics, data analysis, and statistics, solve equations in symbolic form or get numerical results create instant 2D and 3D plots to visualize the results of your calculations, import and export data-both text and graphics-in a variety of standard formats

4.4 Location of optimum positioning of offshore platform hooks [4,5]

This is a single-objective deterministic-based sizing optimization problem. Here the aim is to minimize the weight of the structure (minimize the moment i.e maximum positive moment = absolute value of minimum negative moment) under certain deterministic behavioral constraints usually on stresses and displacements**.** A discrete Deterministic-Based Optimization (DBO) problem can be formulated in the following form:

$$\begin{aligned} &\text{Min} \quad F(s) \\ &\text{Subjected to} \quad g_j(s) \le 0 \quad j = 1,\ldots\ldots,k \\ &s_i \in R^d, \quad i = 1,\ldots\ldots,n \end{aligned} \tag{1}$$

where F(**s**) is the objective function, ***s*** is the vector of design variables, which can take values only from a given discrete set R^d, and g_j (**s**) are the deterministic constraints.

1. The objective of the problem is to minimize the weight of the structure .The weight of the structure is directly related to the moment resisted by the member. In other the

words, we find the optimal hook locations such that the moment is minimized or maximum positive bending moment equal to minimum negative bending moment.

2. To maximize the frequency

In this paper optimum location of lift points on a cantilever beam (Figure 7) and a square grid (Figure 8) is found out considering moment or frequency as objective functions. The design variable, the hook position is represented by 8 bit strings and 8 populations are adopted to start with. ES is applied to maximize the objective function. Since the square grid is doubly symmetric ¼ th of the structure is considered. The results are found to be almost similar. Comparison of the results is shown in Table 1. It is found that optimal hook positions for a cantilever from free end are 0.41 L for both the cases of minimizing the moment and maximizing the frequency. Whereas in the case of square grid, the hook positions from supports are 0.35412 L and 0.52607 L for the case of maximizing the moment and maximizing the frequency, respectively.

Table 1. Comparison of results

Constraint	**Beam**	**Grid**
	Optimum location (X/L)	
Moment	0.41041	0.35412
Frequency	0.40745	0.52667

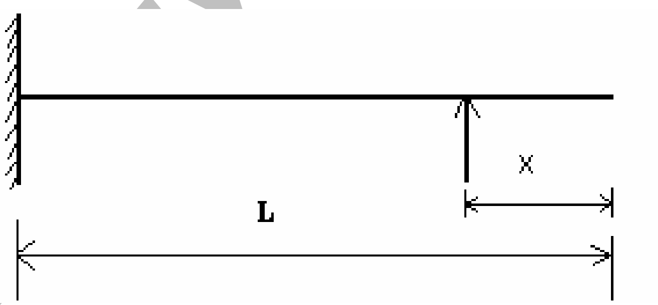

Figure 7. Location of lift point on a cantilever beam

4.5 Optimization of support positions to maximize the fundamental frequency

Generally, more than one support is movable in a prescribed region. Support positions are referred to as design variables. When compared with shape or sizing optimization problems, the number of movable supports is relatively very small. The optimization problem is generally treated as

$$\begin{array}{ll} \textit{Maximize} & \omega_1 \\ \textit{subect to} & \begin{cases} \underline{a}_j \le a_j \le \overline{a}_j & (j = 1, \ldots\ldots, n) \\ a_d = f(a_j) \end{cases} \end{array} \quad (2)$$

where a_j indicates the design variable, representing the co-ordinate of jth independent support position and a_d is a dependent support co-ordinate. The values $\underline{a}_j$ *and* $\overline{a}_j$ denote the lower and upper bounds of the support positions, respectively and 'n' denote the number of movable supports. During the solution process, the fundamental frequency determined by magnitude does not refer to the same vibration pattern. Therefore, the mode switching quite often occurs due to the movement of supports and leads to abrupt change of the frequency sensitivity. Here the finite element analysis part is done through Sap90. The obtained results are optimized using Evolution strategies to maximize the fundamental frequency at the support positions. Both elastic and rigid supports are taken in to account.

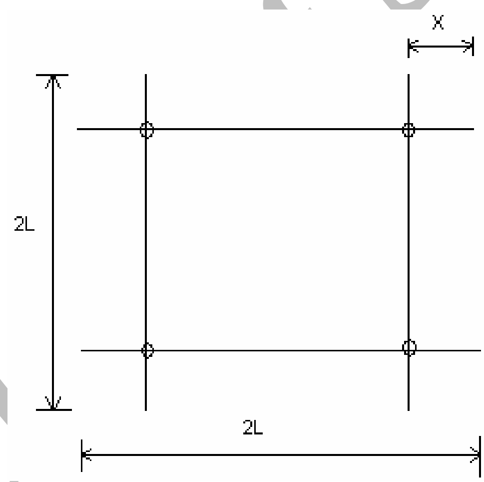

Figure 8. Location of lift point on a square grid

5. Examples

5.1 Location of optimum positioning of offshore platform hooks

Optimum location of heavy lift points can be obtained for different types of grids by minimizing moment or maximizing frequency. Different types of grids are

1. Triangular
2. Rectangular
3. Pentagon
4. Hexagon

5.1.1 Triangular

Model is created in FESAT/PreWin.For the triangular grid the L is taken as 10.The input and output can be obtained by analyzing through FEAST/PreWin. Optimization is performed using the method of Evolution strategies. The same problem is optimized minimizing moment or maximizing frequency as constraints. Triangular grid is shown in Figure 9(a). Graphs can be plotted between variations of moment and frequency with support positions for the triangular grid as shown in Figures 9(b) and (c) and optimal hook positions can be obtained.

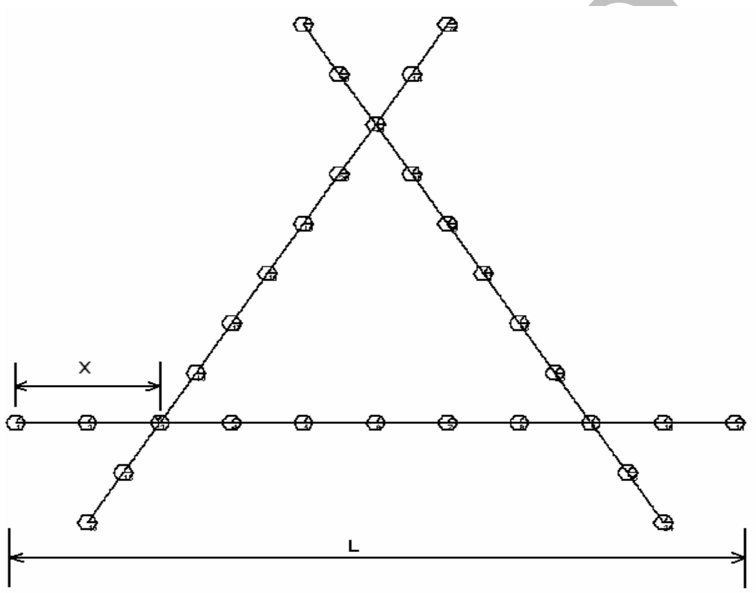

Figure 9(a). Location of lift point on a triangular grid

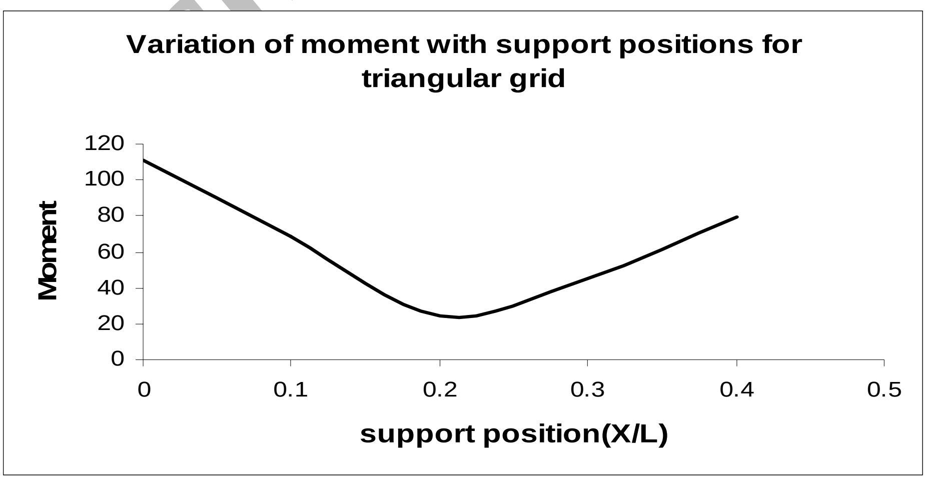

Figure 9(b). Variation of moment with support positions for triangular grid

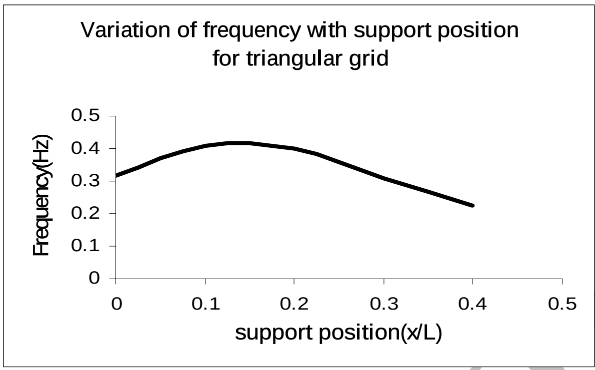

Figure 9(c).Variation of frequency with support positions for triangular grid

5.1.2 Rectangular grid

Model is created in FESAT/PreWin as shown in Figure 10. The input and output can be obtained by analyzing through FEAST/PreWin.Optimization is performed using the method of evolution strategies. Graphs plotted between variations of moment and frequency with support positions for rectangular grid is shown as in Figure 10(a) and 10(b), respectively.

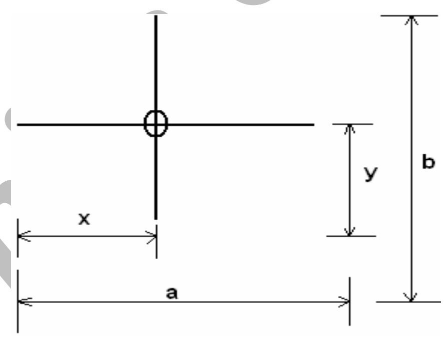

Figure 10(a). 1/4 of the grid is considered

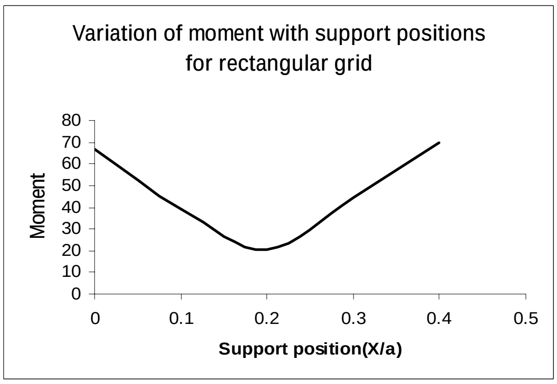

Figure 10(b). Variation of moment with support position for rectangular grid

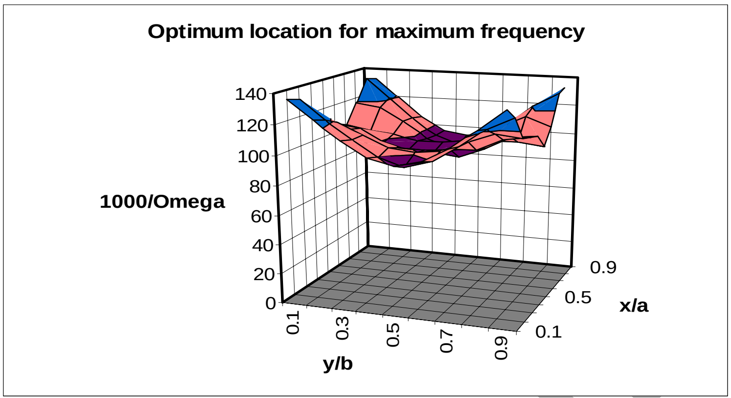

Figure 10(c). Optimum location for maximum frequency for rectangular grid

5.1.3 Pentagon grid

Model is created in FESAT/PreWin as before. .The input and output can be obtained by analyzing through FEAST/PreWin. Optimization is performed using the method of Evolution strategies. The same problem is optimized minimizing moment or maximizing frequency as constraints. For the pentagon L is taken as 10. Variation of moment and frequency with support positions for pentagon are shown Figure 11(a) and (11)b. respectively.

5.1.4 Hexagon

Model is created in FESAT/PreWin as shown before. The input and output can be obtained by analyzing through FEAST/PreWin.Optimization is performed using the method of Evolution strategies. L is taken as 10 for hexagon grid. Variation moment and frequency with support position are plotted as shown in Figure 12(a) and 12(b) respectively.

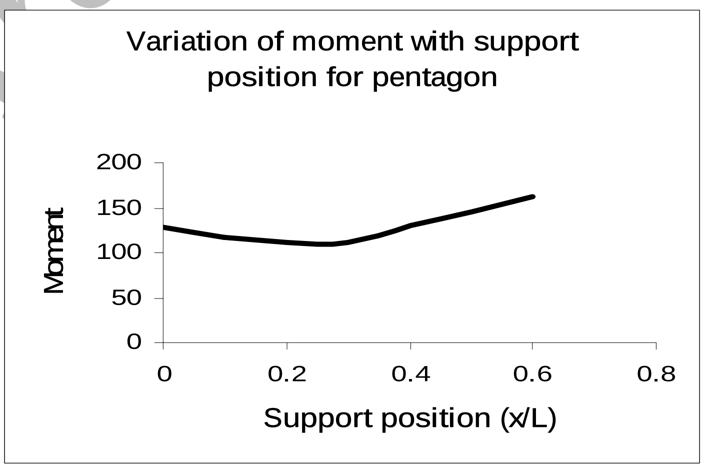

Figure 11(a). Variation of moment with support position for pentagon

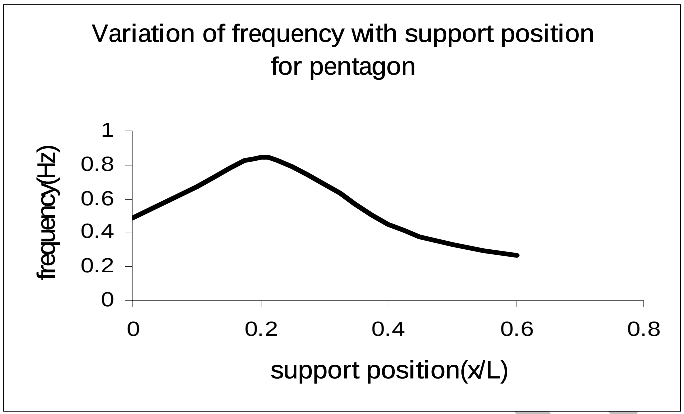

Figure 11(b).Variation of frequency with support position for pentagon

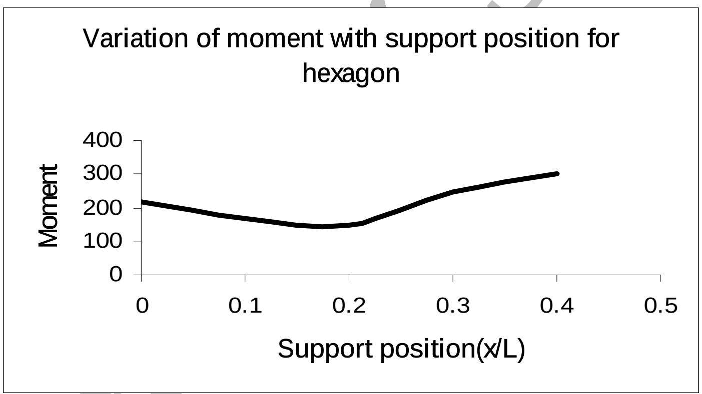

Figure 12(a). Variation of moment with support position for hexagon

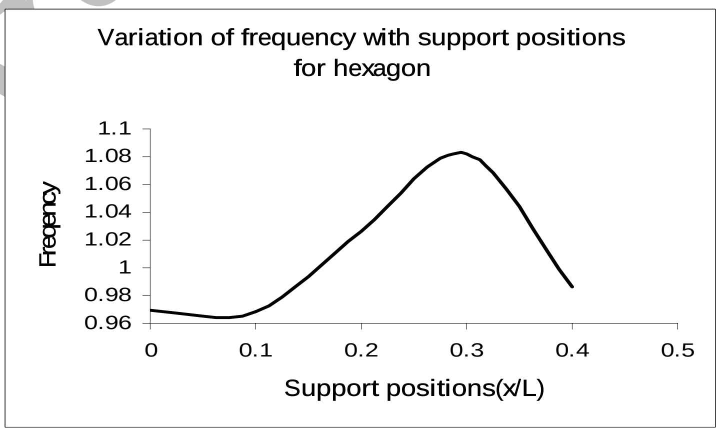

Figure 12(b). Variation of frequency with support positions for hexagon

6. Optimization of Support Positions to Maximize the Fundamental Frequency

6.1 Cantilever beam with additional support [11]

A uniform cantilever beam of length L= 10m, with a lumped mass attachment m=500kg at its mid point, shown Figure 13 The beam is discretized with 16 regular beam elements and is required to maximize its first fundamental frequency by introducing an additional support. The cross-section of the beam is a square with its side of H=0.2 m.Young's modulus is E=210 GPa and material density ρ = 7800kg/m^3. Three different stiffnesses 2.8×10^6 N/m, 5.6 ×10^6 N/m and infinite(rigid support) are used in this problem. Finite element analysis is performed using SAP 90. Then the support position is optimized using Evolution strategies and the results are shown in Table 2.

Table 2. Maximum fundamental frequencies and optimal Support Positions with different support stiffness for the cantilever beam

Optimum design	**Support stiffness(N/m)**		
	2.8×10^6	**5.6×10^6**	**Rigid**
First frequency (Hz)	6.63	8.51	9.19
Support position (m)	8.224	7.702	7.573

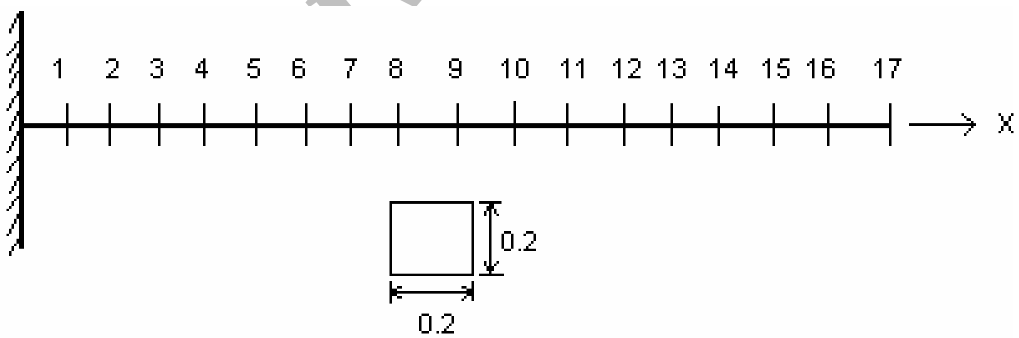

Figure 13. Uniform cantilever beam and its FE model

6.2 Simply supported square plate [10]

A square plate symmetrically supported at four points on the diagonals, as shown in Figure 14. Plate geometry size is L=305mm and thickness is 3.28mm.the plate is discretized with fine mesh quadratic elements as shown Figure 14(b). Young's modulus is E=73.1Gpa, Poisson ratio ν=0.3 and material density ρ = 2821kg/m^3. The four rigid supports move symmetrically along the diagonals to maximize the fundamental frequency of the system. Maximum fundamental frequency at different nodes is shown in Table 3. Finite element analysis is performed using SAP 90. Then the support position is optimized using Evolution strategies. Variation of fundamental frequency and support positions are shown in Figure 15.

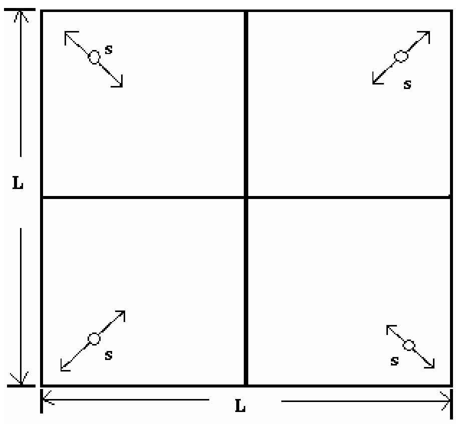

Figure 14(a). Simply supported square plate

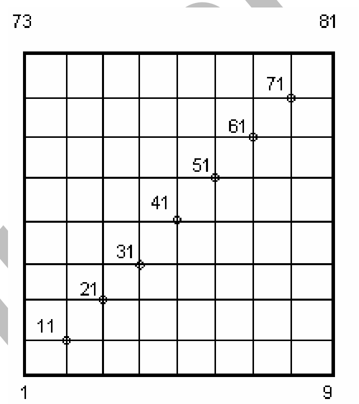

Figure 14(b). One part of square plate is FE meshed

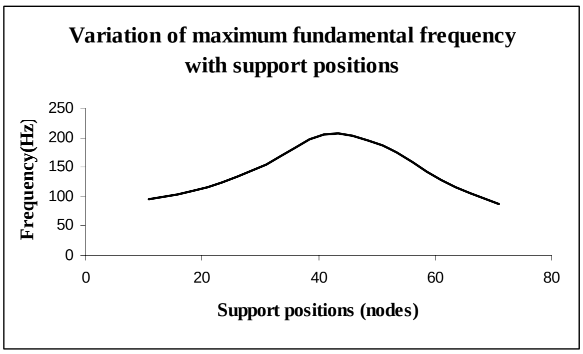

Figure 15. Variation of fundamental frequency with support positions

6.3 Square plate with support shifted along the diagonal

Consider the same square plate in the above problem with support positions shifted along the diagonal(such that B and D are symmetrical, C and D are symmetrical) as shown in Figure 16 Positions of A and D are determined. The finite element analysis is performed using Prawn/FEAST. Variation of frequency with support position can be plotted as shown in Figure 17 at a= 0.05 Lone gets maximum frequency as 233.39 Hz. (a=b=0.15L)

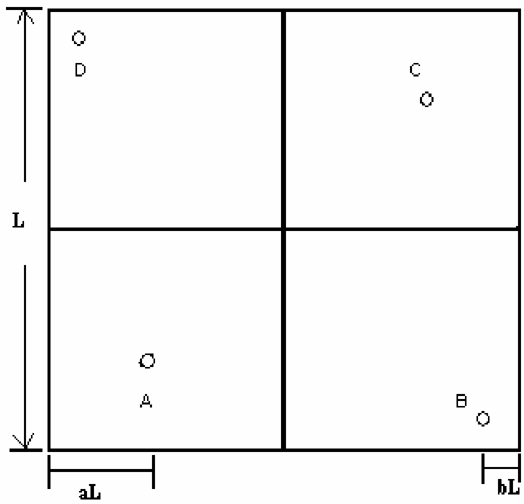

Figure 16. Square plate with support points shifted along the diagonal

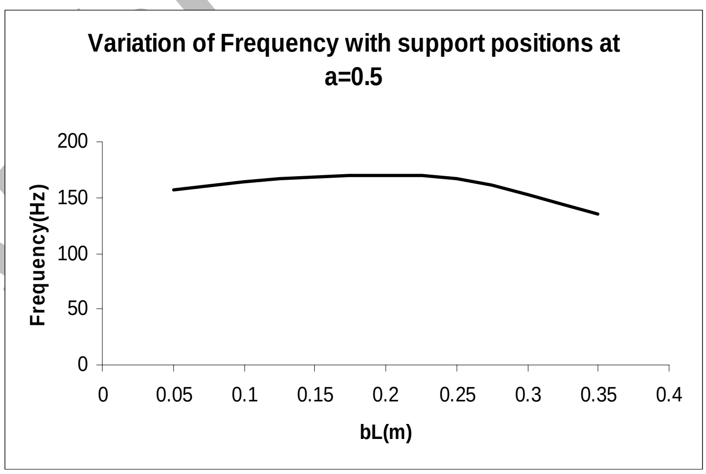

Figure 17. Variaion of frequency with support positions a=0.05

6.4 Maximizing the natural frequency of a beam with an intermediate elastic support [11]

The minimum stiffness of an additional support required to maximize the natural frequency is of particular interest in engineering applications since producing a support with infinite stiffness is virtually impossible. Thus, designing an elastic support at the optimum position that gives a similar effect to the rigid support has significant advantages. This study derives the closed-form solution for the minimum stiffness using using the derivatives of a natural frequency with respect to the support position. This method can be extended to the higher natural frequencies.

Table 3. Maximum fundamental frequency (simply supported plate)

Support position Node No	Frequency (Hz)
11	95.58
21	116.49
31	153.72
41	205.63
51	187.47
61	128.23
71	87.659

6.5 Cantilever beam

Consider a uniform cantilever Euler-Bernoulli beam with flexural rigidity EI, mass per unit length m and length L as shown Figure 18. An elastic support with stiffness k is located at x=b.

The eigenvalue equation for vibration

$$w^4(x) - \lambda^4 w(x) = 0 \tag{3}$$

$$\lambda^4 = \frac{\omega^2 mL^4}{EI} \tag{4}$$

and w(x) is the transverse displacement of the beam,ω the natural (circular) frequency of the vibration and λ the frequency parameter. The general solution to Eq. (3) for cantilever beam is defined separately over the either side of the support location, $w_1(x)$ and $w_2(x)$ respectively. Applying the clamped boundary condition to $w_1(x)$ and free boundary condition to $w_2(x)$ general solution can be obtained.

$$w_1(x) = C_1 \left[\sinh \lambda x - \sin\lambda x\right] + C_2 \left[\cosh \lambda x - \cos\lambda x\right] \quad \text{for } 0 \le x \le b, \tag{5}$$

$$\begin{aligned} w_2(x) = {} & C_3\left[\sinh \lambda(x-1) + \sin \lambda(x-1)\right] \\ & + C_4 \left[\cosh \lambda(x-1) + \cos \lambda(x-1)\right] \quad \text{for } b \le x \le 1 \end{aligned} \tag{6}$$

Consider the cantilever in Figure 9. If the support is located at *b*L makes the slope of the first mode equal to zero at *b*.Then from Eqs. (5) and (6),

$$w_1'(b) = C_1\,\lambda\left[\cosh\lambda b - \cos\lambda b\right] + C_2\,\lambda\left[\sinh\lambda b + \sin\lambda b\right] = 0 \qquad 7(a)$$

$$w_2'(b) = C_3\,\lambda\left[\cosh\lambda(b-1) + \cos\lambda(b-1)\right] + C_4\,\lambda\left[\sinh\lambda(b-1) + \sin\lambda(b-1)\right] = 0 \qquad 7(b)$$

and thus

$$C_2 = -C_1\,\frac{\cosh\lambda b - \cos\lambda b}{\sinh\lambda b + \sin\lambda b} \qquad \text{and} \;\; C_4 = -C_3\,\frac{\cosh\lambda(b-1) + \cos\lambda(b-1)}{\sinh\lambda(b-1) - \sin\lambda(b-1)} \qquad (8)$$

Applying the continuity conditions of displacement at support position we get

$$C_1\,\frac{2\cosh\lambda b\cos\lambda b - 2}{\sinh\lambda b + \sin\lambda b} = -C_3\,\frac{2\cosh\lambda(b-1)\cos\lambda(b-1) + 2}{\sinh\lambda(b-1) - \sin\lambda(b-1)} \qquad (9)$$

Non-trivial solutions for C_1 and C_3 in Eq. (9)

$$\begin{vmatrix} \cosh\lambda b\cos\lambda b - 1 & \cosh(b-1)\cos\lambda(b-1) + 1 \\ \sinh\lambda b\sin\lambda b & \sinh(b-1)\sin\lambda(b-1) \end{vmatrix} = 0 \qquad (10)$$

The continuity of the shear forces at the support location is used to determine the minimum support stiffness.

$$\gamma = \frac{w_1'''(b) - w_2'''(b)}{w_1(b)} \qquad (11)$$

Positioning an elastic support at different nodes of cantilever beam shown in Figure 18, the values obtained for maximum frequency and minimum support stiffness for both cantilever and simply supported beam are shown in Table 4. For solving this problem Mathematica a symbolic processing tool is used. Various plots are made between minimum support stiffness and fundamental frequency, respectively, verses the support position as shown if Figure 19 and Figure 20, respectively.

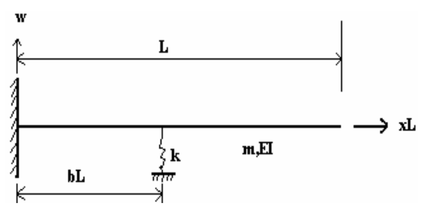

Figure 18. Uniform cantilever beam with intermediate support

6.6 Simply supported beam

A simply supported beam with an intermediate support the beam displacement can be written as similar to cantilever beam.

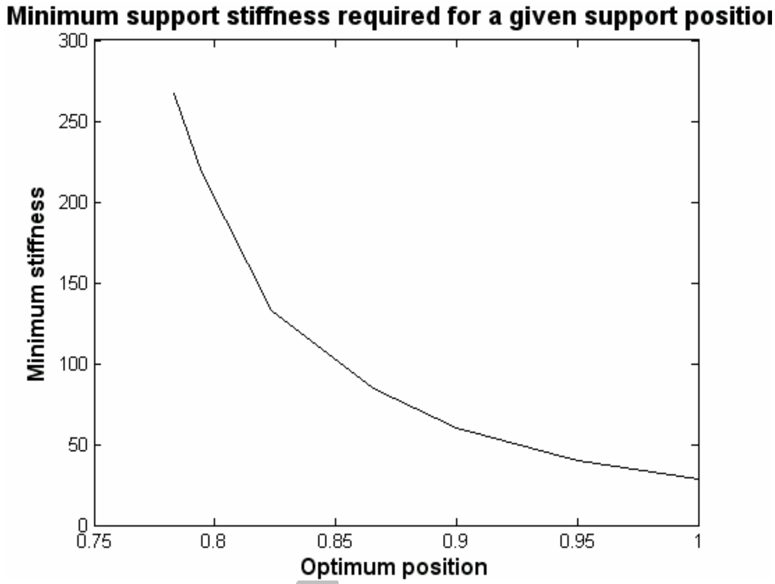

Figure 19. Minimum support stiffness required for a given support position

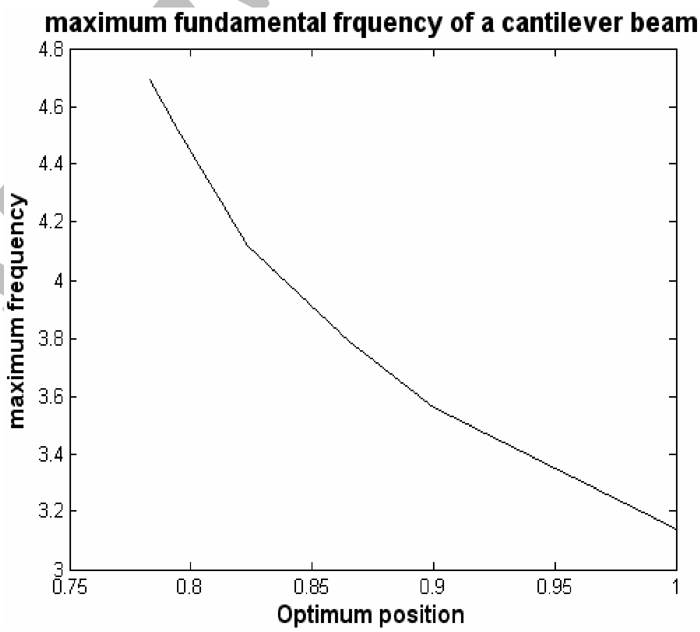

Figure 20. maximum frequency of cantilever beam achieved for a given support position with

minimum stiffness

For clamped beam the resulting equation is

$$\begin{vmatrix} \sinh\lambda b\cos\lambda b - \cosh\lambda b\sin\lambda b & \sinh\lambda(b-1)\cos\lambda(b-1) - \cosh\lambda(b-1)\sin\lambda(b-1) \\ \sinh\lambda b\cos\lambda b + \cosh\lambda b\sin\lambda b & \sinh\lambda(b-1)\cos\lambda(b-1) + \cosh\lambda(b-1)\sin\lambda(b-1) \end{vmatrix} = 0 \quad (12)$$

For different *b* values, maximum frequencies and support stiffness is shown in Table 5.

The lowest natural frequency of a uniform beam may be maximized for different set of end conditions. Maximum frequencies and optimal Support positions with different support stiffness for different end conditions are shown in Table 5.

The notations for the end condition is C = clamped, S=simply supported, SI = sliding, F=free .The problems were solved using Mathematica, a symbolic processing tool.

Table 4. Maximum frequencies and optimal support positions with different support stiffness for the beam

Support	b	Maximum frequency λ	Minimum stiffness γ
cantilever	0.7834	4.6941	266.87
Simp-sup	0.5	6.283	995.91
cantilever	0.8654	3.78526	84.824
Simp-sup	0.75	6.283	0
Cantilever	1	3.1415	28.44

Table 5. Maximum frequencies and optimal Support positions with different support stiffness for different end conditions

End conditions	Support positions (b)	Maximum frequency (λ)	Minimum stiffness (γ)
C-C	1/2	7.885321	1833.66
C-SS	0.5575	7.0681	1377.60
C-SI	0.7168	5.4977	619.39
C-F	0.7834	4.6941	266.87
S-S	1/2	2π	995.91
S-S1	2/3	$3\pi/2$	402.03
S-F	0.7358	3.9263	163.55
SI-SI	1/2	π	113.75
SI-F	0.5517	2.3731	33.491

7. Conclusions

In this paper the optimum location of offshore platform lift points are determined considering moment and frequency as objective functions. Optimum positions of lift points found by minimizing moment or maximizing frequency were almost similar. The study can be extended to different types of grids. Frequency sensitivity with respect to a simple support was investigated. In this study, the analytical formulation of the minimum support stiffness is developed for different types of beam-end conditions based on connectivity conditions at the support point. For this symbolic processing tool Mathematica was used. Finite element analysis is performed using PreWin/FEAST, SAP90 and optimization is performed using Evolution strategies.

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