Stop and pass bands in cross-stiffened plates

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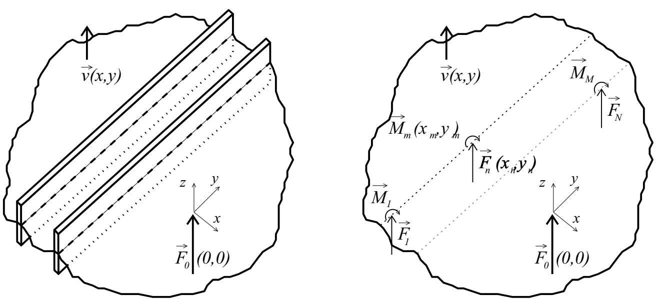
Introduction

Stiffened plates are widely used in engineering practice to achieve sturdy and lightweight structures. Extensive research has been directed towards the propagation of sound in parallel stiffened plates and shells using one-dimensional theoretical models (e.g. [1]) and introducing the effects of periodicity (e.g. [2]). These approaches are not useful in analysing cross-stiffened plates with a non periodic design.

A method of substition forces and moments has been developed to calculate the transfer mobility of parallel and crosswise stiffened, infinite plates. The effect of stop and pass bands is determined with respect to the angle of incidence and layout of the stiffeners. The concept was introduced last year at the DAGA 2007 [3]. This paper will focus on the effects of stop and passbands in cross-stiffened plates compared to parallel stiffened ones with respect to the angle of incidence. In this step regular alignment was investigated, but the concept is not limited to this.

Concept of substitution forces and moments

The model consists of an infinite, thin plate with stiffeners attached as shown in Fig. 1(a). The stiffeners are infinite beams with a rectangular profile. The plate is excited with a point-force, which is acting perpendicular to the plate in the origin of the coordinate system.



(a) plate with stiffeners

(b) plate with substitution forces and moments

Figure 1: Model of the structural system.

The structural influence of the stiffeners is introduced by substitution forces and moments (Fig. 1(b)).The following simplifications are applied:

(a) the shear stress in the plate and the beams is neglected (Kirchhoff bending theory, Euler Bernoulli beam),
(b) the neutral layers of the beams are located at the neutral layer of the plate, and
(c) the stiffeners are mounted either parallel or crosswise parallel on the plate.

The basic structure is the infinite plate. Therefore the wave propagation in an unstiffened, infinite plate is calculated first by means of the transfer mobility of the plate $Y_{vF}^{\infty}(0,0|x,y)$ multiplied with the excitation force F_0. The influence of the stiffeners is added with the partial velocities $F_n\ Y_{vF}^{\infty}(x_n,y_n|x,y)$ and $M_m\ Y_{vM}^{\infty}(x_m,y_m|x,y)$ caused by the substitution forces F_n and moments M_m, where Y_{vM}^{∞} is the cross transfer mobility of the plate. Hence the velocity at a given point (x,y) is obtained by means of a superposition of the excitation force and all substitution forces and moments. In general it can be calculated as

$$v(x,y) = F_0\ Y_{vF}^{\infty}(0,0|x,y) - \sum_{n=1}^{N} F_n\ Y_{vF}^{\infty}(x_n,y_n|x,y) - \sum_{m=1}^{M} M_m\ Y_{vM}^{\infty}(x_m,y_m|x,y) \quad (1)$$

To calculate the substitution forces F_n and moments M_m one has to establish a set of equations, which allows for

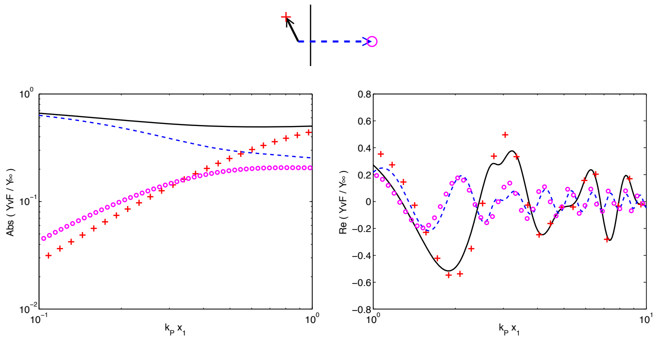
(a) all paths of transmission (plate, stiffeners),
(b) all excited wave types (bending waves in the plate, bending and torsional waves in the beams),
(c) the wave conversion at the points of intersection.

A description how to set up these equations can be found in [4].

Benchmarking

First the simple fashion of a single stiffened plate is calculated. The height of the beam is $h_B = 10h_P$ and the width $b = h_P$. In Fig. 2 one can see the excitation force and the elected receiver points. In [5] an infinite plate with a T-intersection is investigated. The T-intersection is modelled as a simple support of the plate. The support is introduced into the wave equation as a line force. The validity of the model is proven with measurements in [6].

The predicted transfer mobilities of the two methods differ in the low frequency region (Fig. 2(a)). The distance between the excitation point and the stiffener is low in terms of wave lenghts. As the simple support retains the vertical displacement of the plate, the transfer mobilities converge to zero with decreasing frequency. In the model of substitution forces and moments the stiffening just decreases the input mobility of the plate compared



(a) low frequencies (b) mid and high frequencies

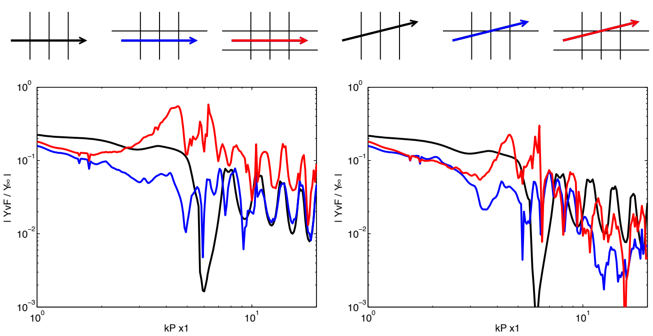
Figure 2: Transfer mobility of a single stiffened plate. The results (solid and dashed lines) are compared with that of a simply supported plate (markers: +, o).

to an unstiffened one. The transfer mobility of the system converges to one, which is the point mobility of an unstiffened plate, or due to the additional stiffening a value just below one.

In the mid and high frequency region the wave propagation between the excitation and the stiffener becomes more and more important. The two models can be validated by each other. The results show very good agreement in the real and imaginary part. Exemplary the real part is shown in Fig. 2(b).

Differences occur at the frequency of $k_P x_1 \approx 3$. This is due to the coincidence of the bending waves of the plate and the torsional waves of the stiffening beam. In the case of the simply supported plate no torsional waves in the stiffeners are modelled and therefore no coincidence phenomenon can be seen.

Simulations



(a) perpendicular incidence (b) oblique incidence

Figure 3: Stiffened plate with 3 parallel beams (black curve), 1 additional crossing beam (blue curve), 2 crossing beams (red curve).

The transfer mobility of a plate with three parallel stiffeners is calculated. One or two crossing beams are added. In Fig. 3 the results for wave incidence perpendicular to the three parallel stiffeners and for oblique wave incidence is shown.

In the low frequency region the patterns are linear as the bending wave lengths of the plate are much bigger than the distances between the discontinuities. In the mid and high frequency region the parallel stiffened plate shows regular and distinct stop and pass bands. The absolute minimum of the curve is related to the coincidence phenomenon described in the latter section. This effect diminishs if crossing beams are added.

For the cross-stiffened plates stop and pass bands can also be seen, but they are not as regular and distinct as for the parallel stiffened plate. Especially in the mid frequency region, where the wave lengths of the plate are in the order of magnitude of the distances between the stiffeners, the minima are small banded in frequency. This minima are related to specific frequencies and can be seen as eigenmodes of the two-dimensional structure. Standing waves can be found in the fields of the plate, which are enclosed by stiffeners.

In the high frequency region several wave lengths fit in between the stiffeners. The structural behaviour of the cross-stiffened plate is determined by the periodicity of the system. The stop and pass bands are similar to that of the parallel stiffened plate. The overall mobility of the plate with two crossing beams and perpendicular incidence (Fig. 3) is higher than that of the others due to the channeling effect of the two stiffeners which line the propagation path.

In the case of oblique wave incidence (Fig. 3(b)) no regular stop and pass bands can be seen, if there is only one crossing beam. Adding the second beam, the stop and pass bands reappear, but they are not as regular as they are in Fig. 3(a), where perpendicular wave incidence is assumed.

Concluding remarks

A concept of substitution forces and moments has been derived to calculate the wave propagation in parallel and cross-stiffened plates. Parallel stiffened plates show regular and distinct stop and pass bands. Cross stiffened plates have similar behaviour for perpendicular wave incidence or strictly symmetric fashion. The stop and pass bands disappear for oblique wave incidence and non symmetric fashions of the crossing beams.

References

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