BUILDING MECHANICS

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INVESTIGATION OF DYNAMIC PARAMETRS OF SPLIT SKEWED BRIDGE SPANS IN CASE OF LOSS OF CONTACT BETWEEN END BEAM AND ITS SUPPORT

Statement of the problem. In order to get a valid estimate of risks of fracture during the maintenance of simply supported skew slab-and-girder reinforced concrete spans of highway bridges the influence of the supporting skew on the natural frequencies spectrum and the corresponding eigenmodes in case of changing the design model due to loss of contact between beams and support.

Results. Possible loss of contact between one of the marginal beams and its support near the sharp angle during the maintenance of transport facility depending on its type and geometrical parameters is substantiated. Modal and frequency spectrum analysis of spans in case of loss of contact between one of the marginal beams and its support is performed.

Conclusions. The analysis revealed possible loss of contact between marginal beams and support, which increases as the skew angle grows and the width and length of the span reduce. A significant influence of support separation on eigenmodes and frequency spectrum of spans is revealed.

Keywords: highway bridge, simply supported skew spans, reinforced concrete slab-and-girder structures, loss of contact, risk of destruction, dynamic parameters, frequency spectrum, eigenmodes.

Introduction

In service of bridge structures with beam superstructures with skewed end supports there is a frequent failure of areas of end beams at sharp angles of superstructures. These are due to impacts of individual heavy-duty vehicles and superstructure beams possibly detaching from supports.

These are frequent in metal and steel-ferroconcrete spans particularly in non-split static schemes due to small relative efforts of dead loads. They are less likely to occur in ferroconcrete superstructures, however they are more dangerous owing to considerable inertial forces caused by oscillations.

In order to assess failure risks for ferroconcrete superstructures with skewed supports in service of transport structures, it is necessary to consider dynamics of impacts [1, 2]. Responses of spans designed in the shape of a parallelogram depend on the skewed angles and significantly differ from frequencies of ferroconcrete beam bridges with supports perpendicular to its longitudinal axis. The features of stress-strain state of structures with skewed supports under random static loadings are detailed in [3].

In order to study the dynamic behavior of spans under moving loads, it is necessary to analyze dynamic parameters of the investigated skewed plate girder spans [2]: frequency rates and corresponding eigenfrequencies discussed in [4].

The paper deals with particular changes in the spectra of eigenfrequencies and eigenvalues of free frequencies of split ferroconcrete non-diaphragm spans of bridges during loss of contact (detachment) of beams from the support. Detachment of the end beam at the sharp angle of the span depending on the skewed angle is considered.

1. Assessment of the likelihood of the calculation situation

For a quantitative evaluation of the likelihood of the detachment of the span beams under the impact of a temporary load, the components of the response of supports of constant and temporary loads H14 and A14 in different calculation specifications according to СП 35-1330-2011. The calculations considered a number of typical ferroconcrete split arch-ribbed spans with different geometrical parameters and design considerations (length, width, thickness of the arch, diaphragm or no diaphragm).

A statistical analysis was conducted using a calculation software SAP2000 and *Midas Civil* employing the finite element method. The schemes detailed in [4] were utilized in the calculation of shell finite element spans (Fig. 1).

The results of the numerical calculations for one-span ferroconcrete beam superstructures with the length of 12 m of varying width are identified in Table 1. Transverse alignments of beams only in the arch and using transverse diaphragms. The latter options of construction solutions are widely used in bridge construction due to their cost-efficiency [5]. The analysis of the calculation results showed that the largest negative support responses to a temporary load occur in skewed diaphragm spans. They increase as the width of the pathway of a transport structure decreases.

Maximum responses to temporary load are comparable with those to constant loads and thus a greater likelihood of the detachment of the beams from supports in service of transport structures. This makes it necessary to study the effect of loss of contact of carrying beams with supports on changes in eigenfrequencies and corresponding forms of free oscillations. The described effect for skewed spans is due to the redistribution of efforts in the structure as well as skewed and a vehicle's wheels not touching the span simultaneously.

Table 1

Comparison of support responses of beams to temporary and constant loads

Parameters of the configuration of the span				Support responses, kN					
				To constant loads at the skew angle of			To temporary loads at the skew angle of		
Diaphragm	Pathway	Width, m	Number of beams	45^0	67.5^0	90^0	45^0	67.5^0	90^0
-	11.5	13.9	8	144.7	144.7	144.7	–26.5	-24.4	-20.0
-	8	10.6	6	144.7	144.7	144.7	-27.4	-25.5	-20.6
-	4.5	7	4	144.7	144.7	144.7	-30.0	-28.2	-22.6
+	11.5	13.9	8	159.4	156.9	154.5	-101.3	-96.2	-71.3
+	8	10.6	6	159.4	156.9	154.5	-112.6	-106.9	-79.2
+	4.5	7	4	159.4	156.9	154.5	-125.1	-118.8	-88.0

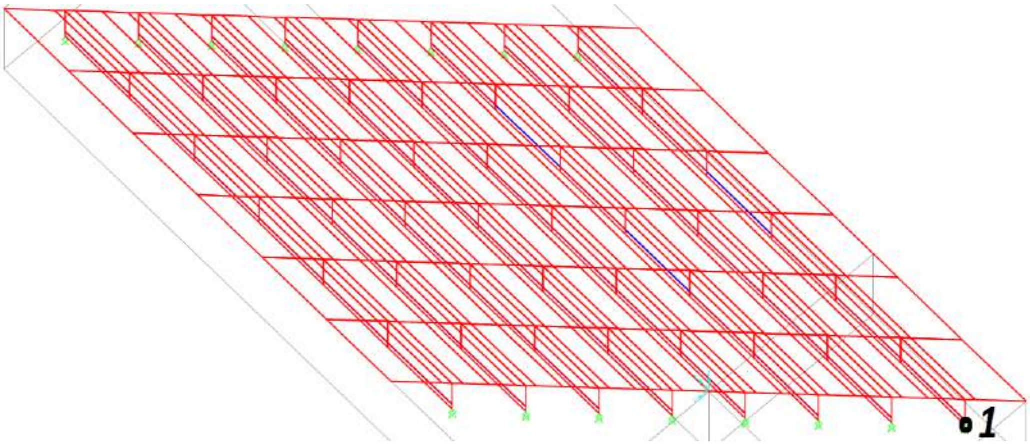


Fig. 1. Shell finite element scheme of the span 1 denotes the point of detachment of the beam from the support

2. Research methods and calculation model

Since a dynamic calculation of spans considering the detachment of the ends of beams from the supports is a complex contact problem faced by building mechanics, an approximated algorithm will be employed based on the method of dividing the solution into free eigenfrequencies. For this purpose, let us examine changes in the oscillation spectra and corresponding eigenvalues with no contact of the span at the sharp angle of the end section of the carrying beam.

A dynamic analysis as well as statistical one was conducted using parts of a modal analysis of calculation software SAP2000 and *Midas Civil*. Dynamic calculation schemes made up of shell finite elements (see Fig. 1) were used. The choice of the calculation scheme was due to the previous research [4].

The objects of the research were typical spans with and without diaphragms of ferroconcrete T-section beams with non-stressed reinforcement Г11.5+0.75 and the length 12 m. The following four skew angle options of the span support were considered 45^0, 60^0, 75^0 and 90^0.

3. Analysis of the calculation results

In order to analyze the results obtained in the numerical study [4], let us remind the following features of eigenvibration spectra and values of ferroconcrete spans with mutual supports that do not depend on the skew angle:

- two lowest eigenvalues are symmetrical and antisymmetrical with a semiwave of a relatively longitudinal axis of a bridge structure;
- eigenfrequencies for the first two eigenvalues are similar. They can be considered multiple;
- there is a regular combination of symmetric and antisymmetric eigenvalues.

The comparative results of the three lowest eigenfrequencies for different spans and skew angles are summed up in Table 2.

The analysis of the calculation results indicated that detachment of the carrying beams at the sharp angle of the span influences eigenfrequencies and corresponding eigenfrequencies of the span.

Table 2

Comparison of eigenfrequencies of spans with different skew angles of support
with and without detachment

h	*v*	Eigenfrequencies, Hz, of the span at the skew angle of							
		90^0	75^0	60^0	45^0	90^0	75^0	60^0	45^0
		For non-diaphragm spans				For diaphragm spans			
Without detachment									
1	0	7.99	8.16	8.5	8.68	7.65	7.81	8.14	8.31
	1	8.01	8.18	8.52	8.69	7.65	7.82	8.15	8.32
	2	10.08	10.3	10.74	10.96	12.29	12.56	13.09	13.36
	3	10.87	11.11	11.58	11.82	14.10	14.41	15.02	15.33
With detachment									
a		3.22	3.29	3.44	3.51	6.45	6.59	6.87	7.01
b		7.65	7.81	8.14	8.31	7.65	7.82	8.15	8.32
a		7.65	7.82	8.15	8.32	—	—	—	—
1	2	12.29	12.56	13.09	13.36	13.98	14.29	14.89	15.20
	3	14.10	14.41	15.02	15.33	15.33	15.58	16.07	16.32

Note: The following denotations are introduced in Table 2: *a* are eigenvalues associated with the frequencies of the end beam with the detachment of the support and adjoining beams; *b* are eigenvalues associated with frequencies of the beams at the end opposite the one where the beam detached from the support; *h* is a number of semiwavwa in the longitudinal direction; *v* is a number of longitudinal nodal line on the span.

The following features should be highlighted:

– in non-diaphragm spans in the lower part of the spectrum there are considerable changes occurring during detachment. Instead of two identical in frequencies symmetrical and antisymmetrical values there are three new ones (Table 2) where there are vibrations of the end beam adjacent to where the detachment occurs (Fig. 3a, c) and beams on the opposite side of the span (Fig. 3b). For diaphragm spans changes of eigenvalues and frequencies during detachment are not considerable, the two first values are replaced by two new ones just as for non-diaphragm spans (Fig. 4, Table 2);

– the order of the eigenvalues, except for the first and second one does not change much as does the calculation scheme (Table 2);

– if one of the beams is detached, pretty much the same applies for the dependence of eigenvalues on the skew angles (Fig. 2);

– in the smallest eigenvalues during detachment of the beam the amplitudes of eigenvalues adjacent to the sharp angles of the span are considerably larger than those of the same values in the other beams of the span, while this does not apply for the largest values (Fig. 3, 4);

– frequencies of the largest eigenvalues (starting with the third frequency component increase during detachment (Table 2, Fig. 2);

– a skewed angle of the span does not appear to have a significant effect on changes of eigenvalues during detachment (Table 2);

– features of the spectra of eigenfrequencies identified in [5] for spans that did not lose contact with the beam supports are largely sustained during detachment (Fig. 2—4).

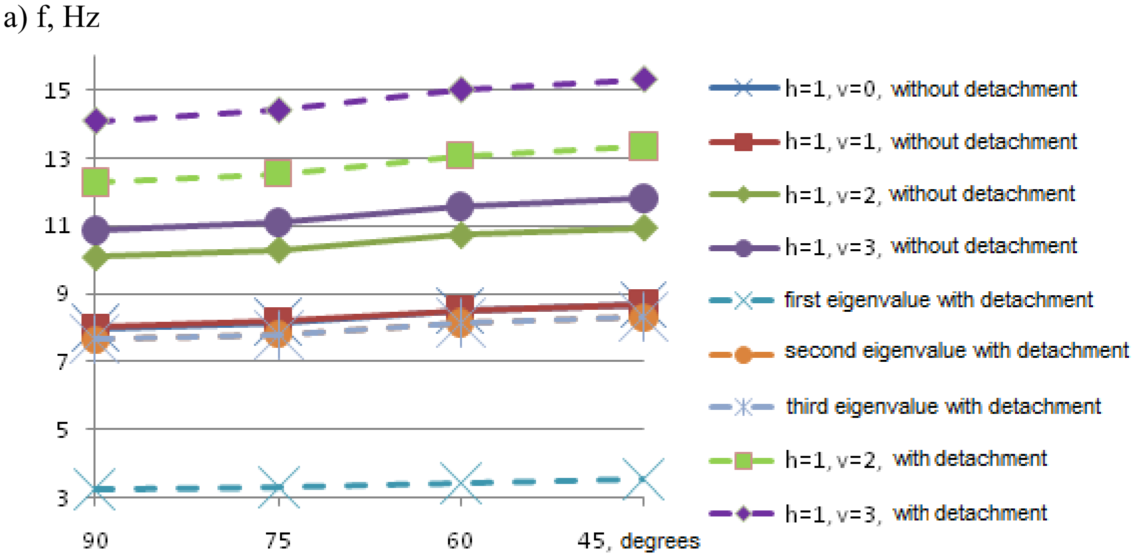


Fig. 2. Graph of changes of frequencies for different eigenvalues of frequencies of the span: a) without diaphragms; b) with diaphragms

b) f, Hz

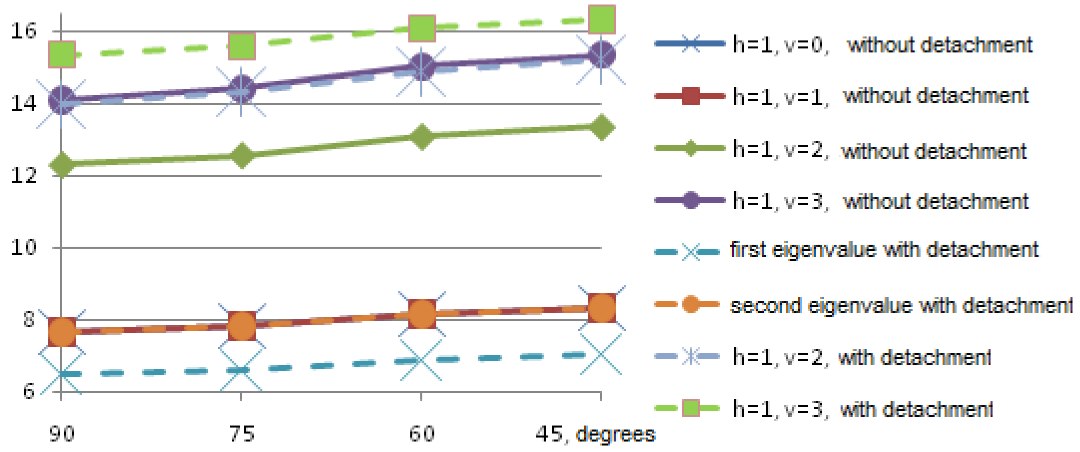


Fig. 2 (ending). Graph of changes of frequencies for different eigenvalues of frequencies of the span: a) without diaphragms; b) with diaphragms

The graphs of changes of frequencies of some of the smallest eigenvalues considering and not considering detachment of beams at the sharp angles of the skewed spans depending on the skewed angle are presented in Fig.3. To make it clear, in Fig. 3a the lines for the parameters $h = 1$, $v = 0$ and $h = 1$, $v = 1$ coincide without detachment and the first and second eigenvalues with detachment. Furthermore, in Fig. 3b the graphs for the parameters $h = 1$, $v = 0$ and $h = 1$, $v = 1$ coincide without detachment and the first eigenvalue with detachment.

The graphs suggest that the frequencies of the end beams of the span of some of the smallest eigenvalues (for a diaphragm span it is the second one and for a non-diaphragm span it is the second and the third one) with detachment are not considerably different from almost identical frequencies of the first two eigenvalues without detachment. The frequencies of the smallest eigenvalues are significantly different.

In order to illustrate the above features of the eigenvalues of frequencies of spans, there are axonometric images in Fig. 3 and 4 (the color scheme in the image relates to the displacements).

Conclusions

1. The calculations indicated a great likelihood of detachment of a beam from the support under temporary wheel loads. A greater likelihood of detachment of beams of a span was revealed as the length and width of the span decreases and also as the longitudinal stiffness of span increases with by means of extra diaphragms.

2. Detachment of carrying beams was found to have a significant influence on the spectrum of eigenvalues and corresponding eigenvalues of non-diaphragm spans. Two smallest eigenvlaues change describing local movements of end beams of the support. The largest eigenvalues do not change considerably during detachment and their frequencies increase.

3. The features of the spectra of the eigenvalues previously identified for beams that did not lose contact with the supports are found to sustain during detachment.

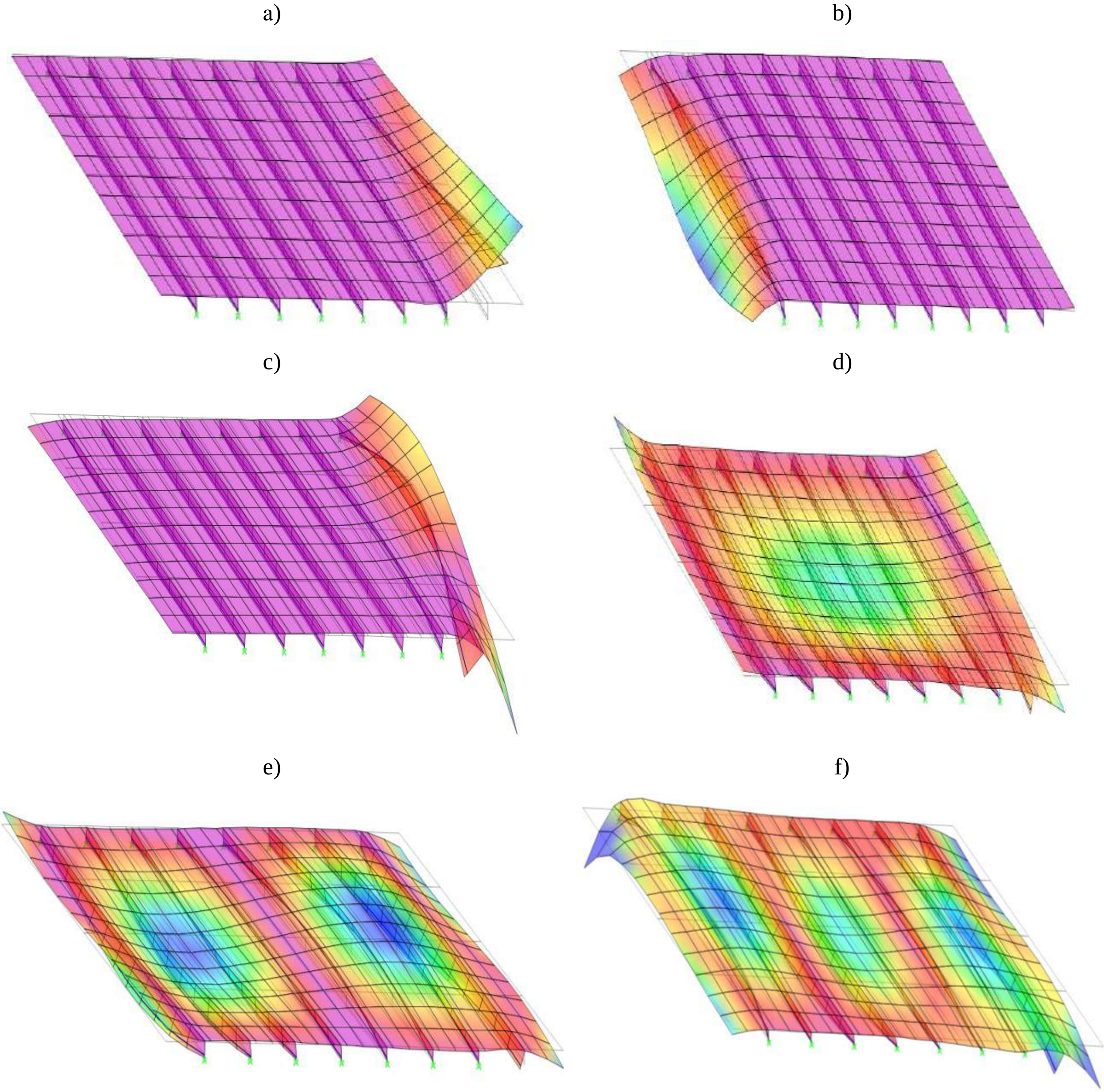
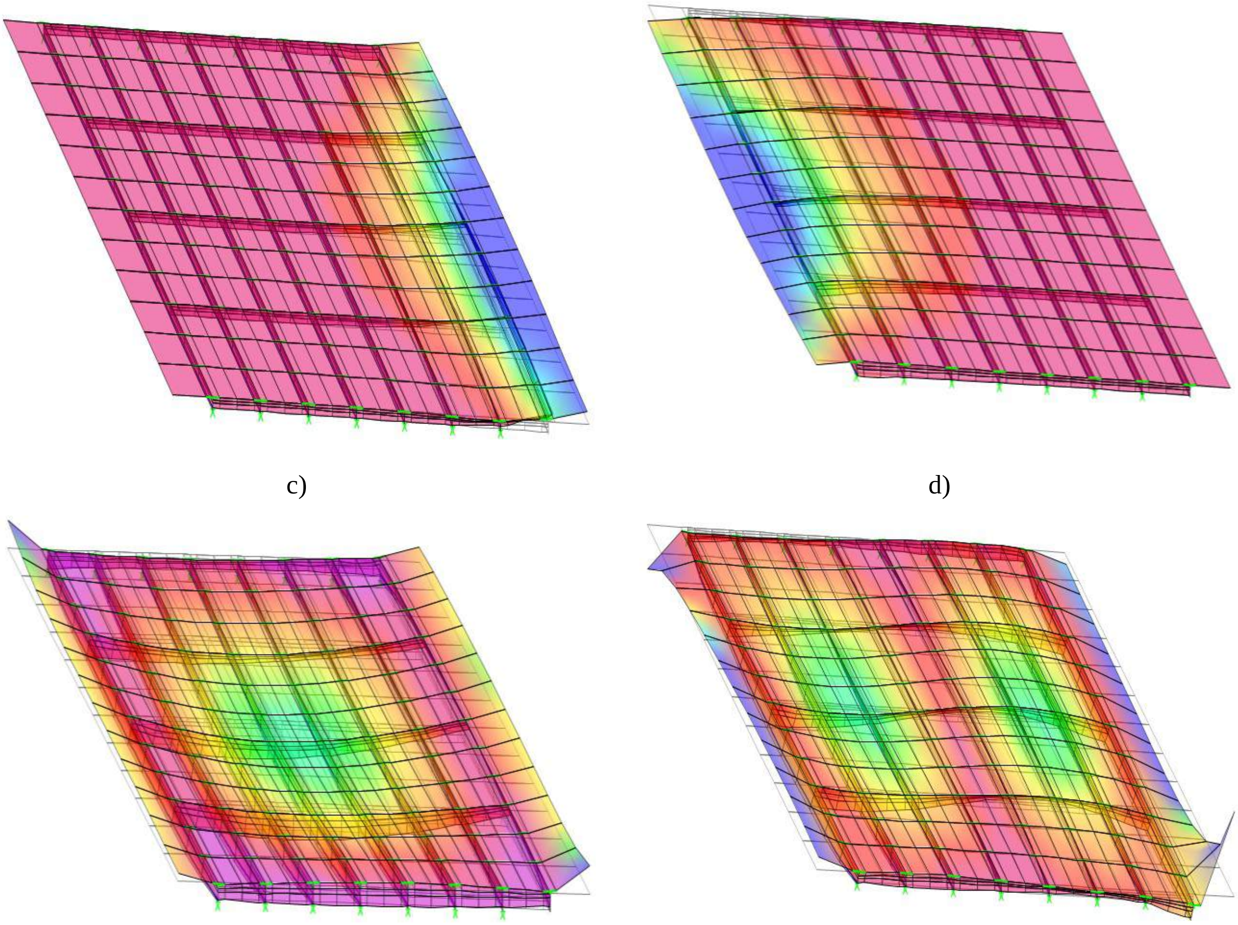

a) b) c) d) e) f)

Fig 3. Eigenvalues of frequencies of a non-diaphragm span with detachment: associated with the frequencies of the side of the span adjacent to where the span detaches from the support (a) and (c) the opposite side (b); with no significant changes (d), (e), (f)



a) b) c) d)

Fig 4. Eigenvalues of frequencies of a diaphragm span with detachment:
associated with the frequencies of the span adjacent to the support (a) and the opposite side (b);
largest eigenvalues with no significant changes (c), (d)

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