

RESEARCH REPORT

Centre de recherche en génie parasismique et en dynamique des structures

STATIC AND DYNAMIC COMPRESSION TEST OF HEVEA ANTIVIBRATION BEARINGS

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Static and dynamic compression tests of
HEVEA antivibration bearings

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Summary

This report presents the experimental characterization tests for two natural rubber antivibration bearings, conducted on January 18th 2008 and February 19th 2008 by the CRGP (Centre de recherche en génie parasismique et en dynamique des structures) at the Université de Sherbrooke (Canada, QC). These tests were carried out for Produits HEVEA Inc., bearings supplier, and took place in the structures laboratory of the Civil Engineering Department. The main purpose of these tests was to determine the static and dynamic compression stiffnesses of the bearings, following a predefined testing procedure.

The report first describes the experimental setup for the static and dynamic tests, including the instrumentation. The experimental characterization procedure and the analysis calculations are then presented. Finally, all experimental results (tests curves and calculated values) conclude the report.



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Experimental set-up

This section describes the experimental setup for the static and dynamic tests on natural rubber antivibration bearing manufactured by Produits Hevea Inc.

1.1 EXPERIMENTAL ASSEMBLY

Figures 1.1 and 1.2 illustrate the experimental setup used to characterize the bearings static and dynamic stiffnesses. Two bearings specimens were tested, defined as *Type B* and *Type G* in the following sections. The specimen dimensions are:

- Type B: 360 mm × 360 mm × 79 mm
- Type G: 420 mm × 420 mm × 262 mm

Before testing, the natural rubber bearing specimen is centered on a steel rigid support, specifically designed in order that its deformation is negligible under the testing load levels. Compression loads are applied by an MTS dynamic hydraulic actuator (maximum capacity of 500 kN). The test loads are transmitted from the actuator to the bearing using a stiff steel plate (610 × 610 × 57 mm) ensuring a homogeneous stress distribution on the upper face of the bearing. The actuator is fixed to a vertical steel rigid frame.

1.2 INSTRUMENTATION

The measurement of the applied compression load and of the bearing deformation during the test is required to calculate the static and dynamic bearing stiffnesses:

Measurement, at a given instant, of the applied compression load and of the bearing deformation is required to calculate the static and dynamic bearing stiffnesses:

- The load measurement is directly provided by a load cell (static and dynamic, maximum capacity 500 kN) fixed at the actuator rod end. So placed, the load cell is in series between the actuator and the bearing. During a force-controlled test, the force values given by the load cell drive the test.
- 4 LVDTs (Linear Variable Differential Transformer) are placed at the middle of the bearing sides, and give the direct measure of its deformation: each LVDT is fixed to the rigid support giving displacements relative to the lower face of the bearing sitting on the base steel support. Each LVDT's measuring rod is glued to the thick steel plate transmitting the load to the upper face of the bearing. The average of the four deformation values is used to calculate the bearing stiffness and to plot the force vs displacement curves. Only one of the four LVDTs drives the test when displacement-control is required.

The instrumentation is connected to two external computers, one driving the input load while the other is used for data acquisition.

Measurement errors from sensors are:

- Force value of the load cell: ± 2.5 kN (supplier value).
- Deformation value given by the average value of the 4 LVDTs: $[-14e^{-3}, +4e^{-3}]$ mm (laboratory calibration).

1.3 EXPERIMENTAL METHOD AND CALCULATIONS

1.3.1 Experimental method

The experimental test protocol for the determination of the bearings static and dynamic stiffnesses was provided by Produit Hévéa Inc. The steps followed in each test of a bearing specimen are :

1. **Test reset:** The bearing specimen is centered on the rigid support, its internal temperature is measured, and all sensors are reset (zero load at zero displacement in all four LVDTs).
2. **1st static loading:** The bearing specimen is slowly compressed up to the predefined bearing load (182 kN for Type B, 364 kN for Type G). The loading consists in a ramp with a rate of 10 kN/s, and is the actuator is force-controlled during this phase. The acquisition of the load is carried out at a rate of 10 samples/s, and used to calculate a first value of the bearing static stiffness (see calculations). Before the dynamic tests, the compression load is held constant during a period that is sufficient to reach the bearing stability (warping).
3. **Dynamic loading, 0.25 mm, 3 Hz:** The bearing is excited by a sinusoidal signal of 90 cycles, at a frequency of 3 Hz (the total excitation time is 30 s), and a magnitude of 0.25 mm peak-to-peak (mean value being the final deflection after the first static loading). This is a displacement-controlled loading, and data acquisition is carried out at a rate of 500 samples/s. The bearing internal temperature is measured after the dynamic test, and the bearing is left at rest a few minutes to reach its stability before the next dynamic test.
4. **Dynamic loading, 0.25 mm, 10 Hz:** This test is the same as the previous dynamic test, with a magnitude of ± 0.125 mm, a frequency of 10 Hz, and a total of 90 *cycles* (the total excitation time is 9 s). Data acquisition is carried out at 500 samples/s.
5. **Dynamic loading, 0.25 mm, 20 Hz:** This test is the same as the previous dynamic test, with a magnitude of ± 0.125 mm, a frequency of 20 Hz, and a total of 130 *cycles* (the total excitation time is 6.5 s). Data acquisition is carried out at 1000 samples/s.
6. **Unloading:** Unloading of the bearing specimen is done, and all sensors are reset (zero load at zero displacement in all four LVDTs). The bearing internal temperature is measured.
7. **2nd static loading:** This test is exactly the same as the 1st static load test. Data acquisition for this static loading is also carried out in order to calculate a second static stiffness value (see calculations).
8. **Dynamic loading, 0.4 mm, 3 Hz:** This test is the same as dynamic test 0.25 mm 3 Hz, with a magnitude ± 0.2 mm (mean value being the final deflection after the second static loading), a frequency of 3 Hz, a total of 90 *cycles* (total excitation time 30 s), and acquisition is carried out at 500 samples/s.
9. **Dynamic loading, 0.4 mm, 10 Hz:** This test is the same as the previous dynamic test with a magnitude of ± 0.2 mm, a frequency of 10 Hz, a total of 130 *cycles* (total excitation time 13 s). Data acquisition is carried out at 500 samples/s.

10. **Unloading:** Same as previous unloading.
11. **3rd static loading:** The bearing is quickly loaded up to 480 kN (effective maximum capacity of actuator). The loading consists in a ramp with rate of 25 kN/s, and the actuator force-controlled. The compression load is held constant during 15 minutes before unloading. No data acquisition is carried out during this step.
12. **4th static loading:** This test is exactly the same as the previous static loading. After unloading, the bearing internal temperature is measured, and all sensors are reset for the final static loading.
13. **Final static loading:** The bearing is loaded very slowly up to 480 kN (effective maximum capacity of actuator). The loading consists in a ramp with rate of 1 kN/s (loading time of 1.7min for each 100 kN step), and the actuator is force-controlled. Data acquisition is carried out at a rate 1sample/s in order to calculate the bearing specimen's final static stiffness. After loading, the internal temperature of the bearing is measured, and the specimen is unloaded and removed from the experimental setup.

1.3.2 Stiffness calculation

Static stiffness: The first two static loadings and the final static loading are recorded in order to calculate different values of the bearing static stiffness.

The static stiffness determined in the final static loading is the only one required by the customer. Its determination is according to the protocol provided by the customer.

For the first two static loadings, the bearing static stiffness k_{stat} is calculated as the slope of the best straight line through the recorded data points when plotting the load vs deformation curve, considering only the linear part of the curve (data points near to the origin are ignored). Stiffness and force vs displacement curves are calculated and plotted considering the mean deformation value obtained from the 4 LVDTs. The effective bearing deformation Δ_{stat} under the applied compression load f_{max} is then calculated by dividing the maximum applied load by the previously calculated static stiffness:

$$\Delta_{stat} = \frac{f_{max}}{k_{stat}} \quad (1.1)$$

For the final static loading, the bearing static stiffness k_{stat} and the corresponding effective deformation Δ_{stat} are calculated as previously described, but only considering data points in the load vs deformation curve with loads greater than 100 kN.

Dynamic stiffness: Each dynamic test is recorded with a short enough sampling period to detect excitation peaks and to calculate an accurate value of the dynamic stiffness. The excitation curve (average deflection of the specimen vs time) is plotted for each dynamic test in order to determine the useful data range for analysis (corresponding to the data range where recorded mean values of deformation are satisfactorily similar to the desired excitation). Only this useful data range is considered to calculate dynamic stiffness and to plot hysteresis curves. Maximum and minimum load values, f_{max} and f_{min} , and maximum and minimum deformation values, Δ_{max} and Δ_{min} , are extracted from the useful data range to calculate the dynamic stiffness k_{dyn} as:

$$k_{dyn} = \frac{f_{max} - f_{min}}{\Delta_{max} - \Delta_{min}} \quad (1.2)$$

Sensor errors: Sensor accuracy values are given in the first section of this report (force: $[-\delta F; +\delta F] = [-2.5, +2.5]$ kN, displacement: $[-\delta \Delta; +\delta \Delta] = [-14e^{-3}, +4e^{-3}]$ mm). Sensor uncertainties are responsible

for errors $[-\delta k, +\delta k]$ generated in the dynamic stiffness calculation. These errors are given by the following equation:

$$\begin{cases} +\delta k = \frac{+\delta F}{f_{max} - f_{min}} - \frac{-\delta \Delta}{\Delta_{max} - \Delta_{min}} \\ -\delta k = \frac{-\delta F}{f_{max} - f_{min}} - \frac{+\delta \Delta}{\Delta_{max} - \Delta_{min}} \end{cases} \quad (1.3)$$

Figure 1.1 Experimental set-up with bearing Type B



Figure 1.2 Experimental set-up with bearing Type G



Tests results

2.1 BEARING TYPE B

2.1.1 Summary

Test conditions:

- Bearing specimen dimensions for Type B: 360 mm \times 360 mm \times 79 mm ($L \times l \times h$)
- Compression load for dynamic tests: 182 kN

Table 2.1 Static stiffnesses calculated for Type B

Test	Static stiffness (kN/m)
1 st static loading	142209
2 nd static loading	141700
Final static loading	134128

Table 2.2 Dynamic stiffnesses calculated for Type B

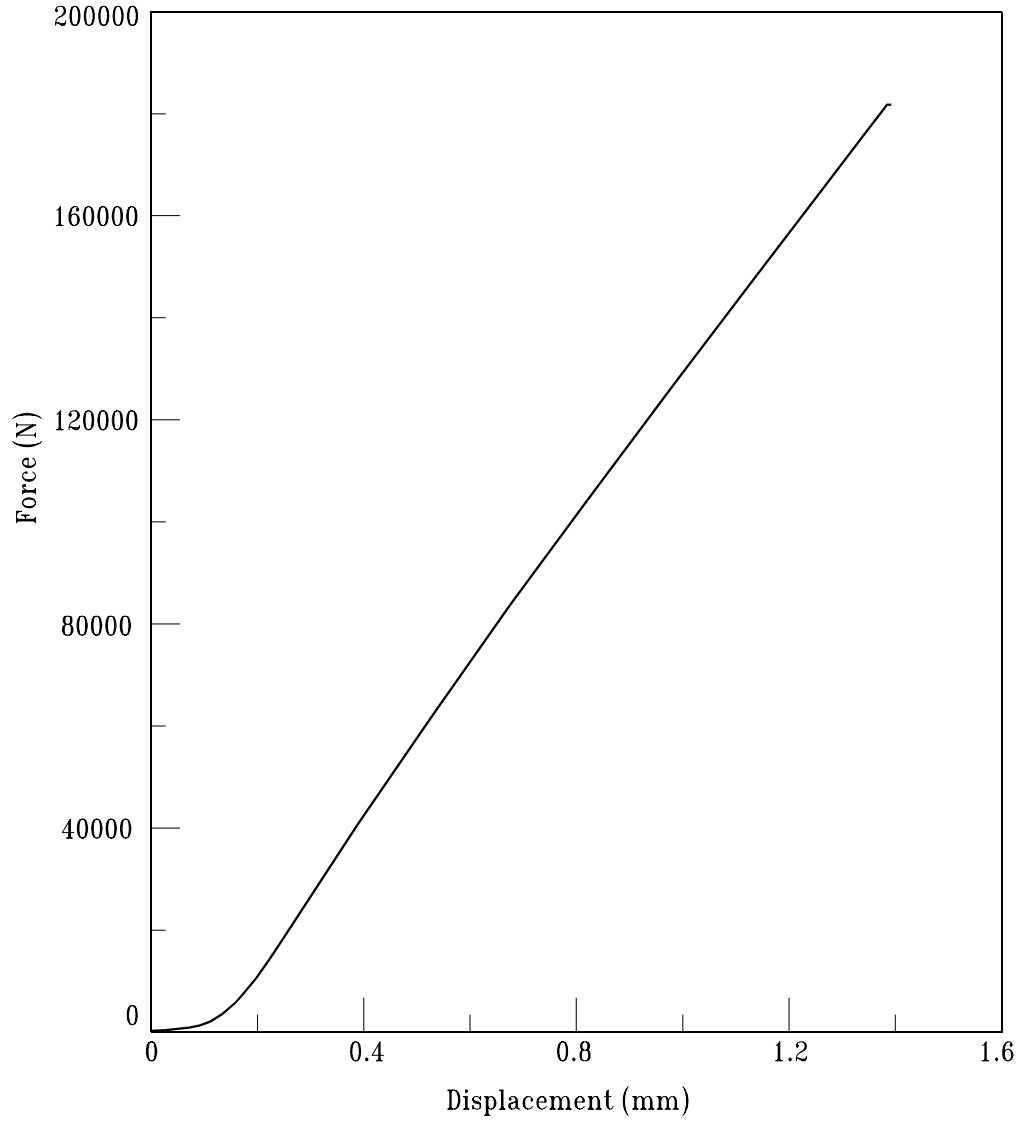
Excitation level (mm)	Frequency (Hz)	Dynamic stiffness (kN/m)	Error (%)
0.25	3	198332	10.0 -6.2
0.25	10	204437	9.5 -5.9
0.25	20	201414	10.1 -6.3
0.4	3	186024	6.3 -4.0
0.4	10	192424	6.2 -3.9

2.1.2 Hysteresis curves and values

1st static loading:

Static stiffness :	142209 kN/m
Deformation under applied load :	1.278 mm

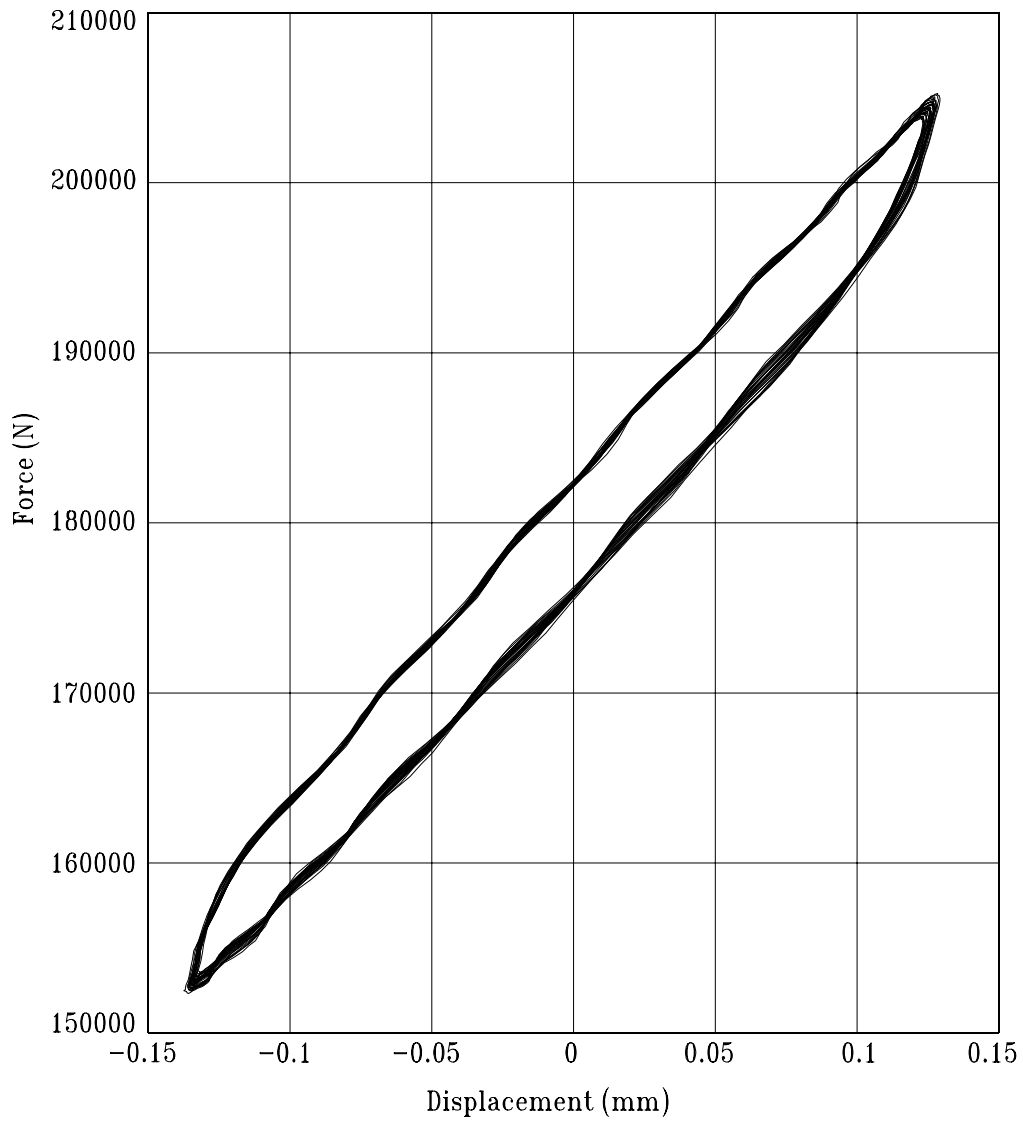
Figure 2.1 Type B - 1st static loading curve



Dynamic loading 0.25 mm, 3 Hz:

	Displacement (mm)	Force (N)
max	0.129	205225
min	-0.138	152320
Dynamic stiffness : 198332 kN/m		

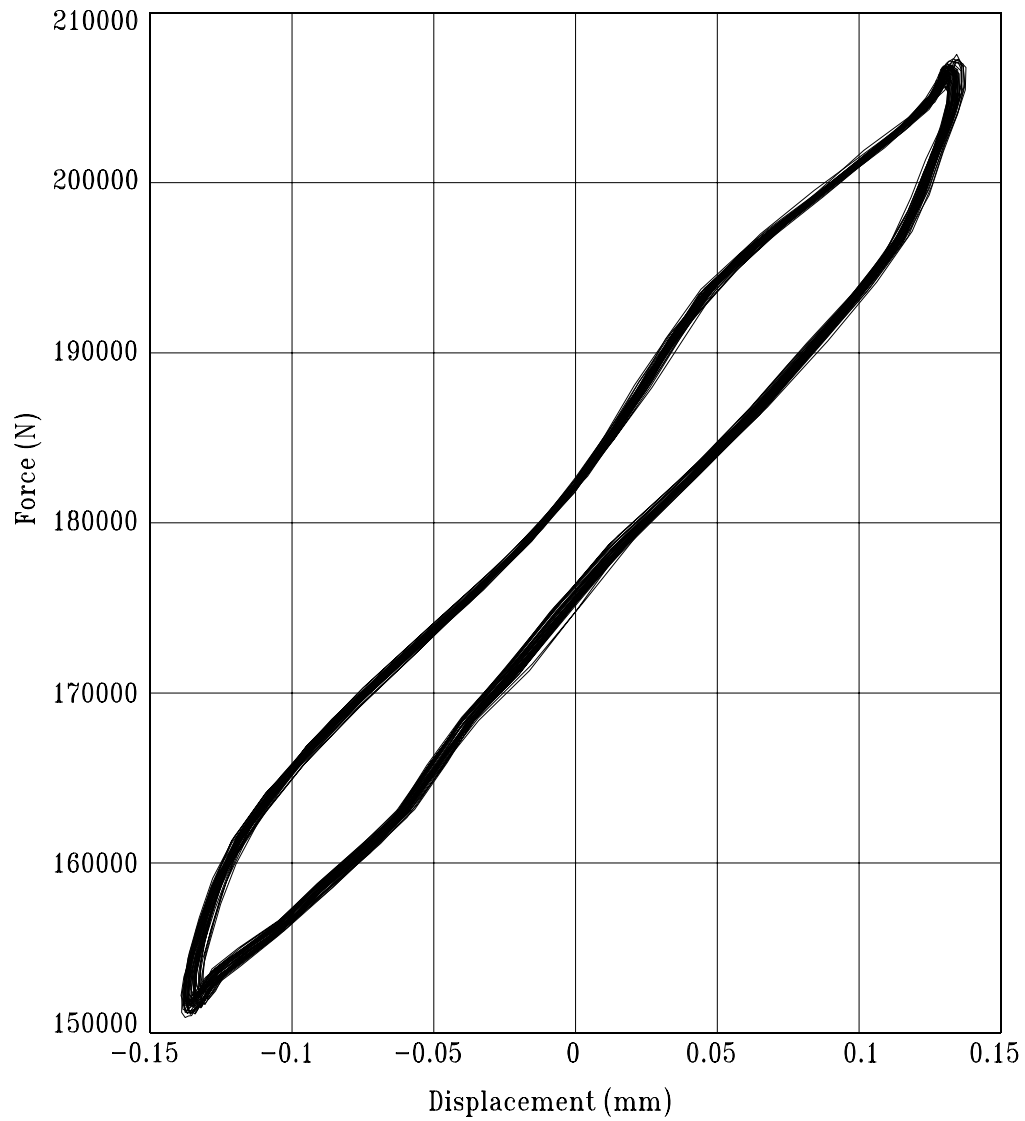
Figure 2.2 Type B - Hysteresis curve: 0.25 mm, 3 Hz



Dynamic loading 0.25 mm, 10 Hz:

	Displacement (mm)	Force (N)
max	0.138	207545
min	-0.139	150916
Dynamic stiffness : 204437 kN/m		

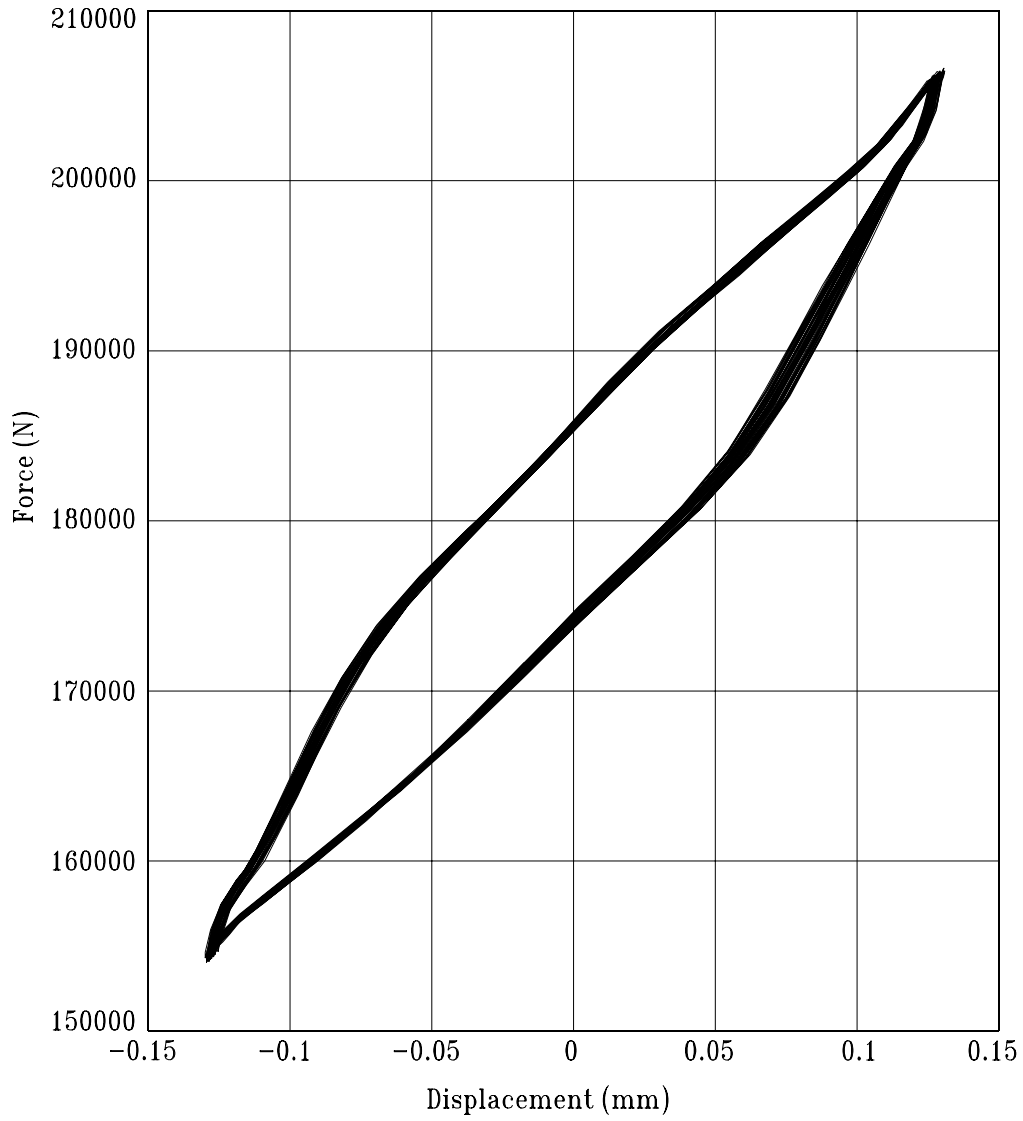
Figure 2.3 Type B - Hysteresis curve: 0.25 mm, 10 Hz



Dynamic loading 0.25 mm, 20 Hz:

	Displacement (mm)	Force (N)
max	0.131	206614
min	-0.130	154045
Dynamic stiffness : 201414 kN/m		

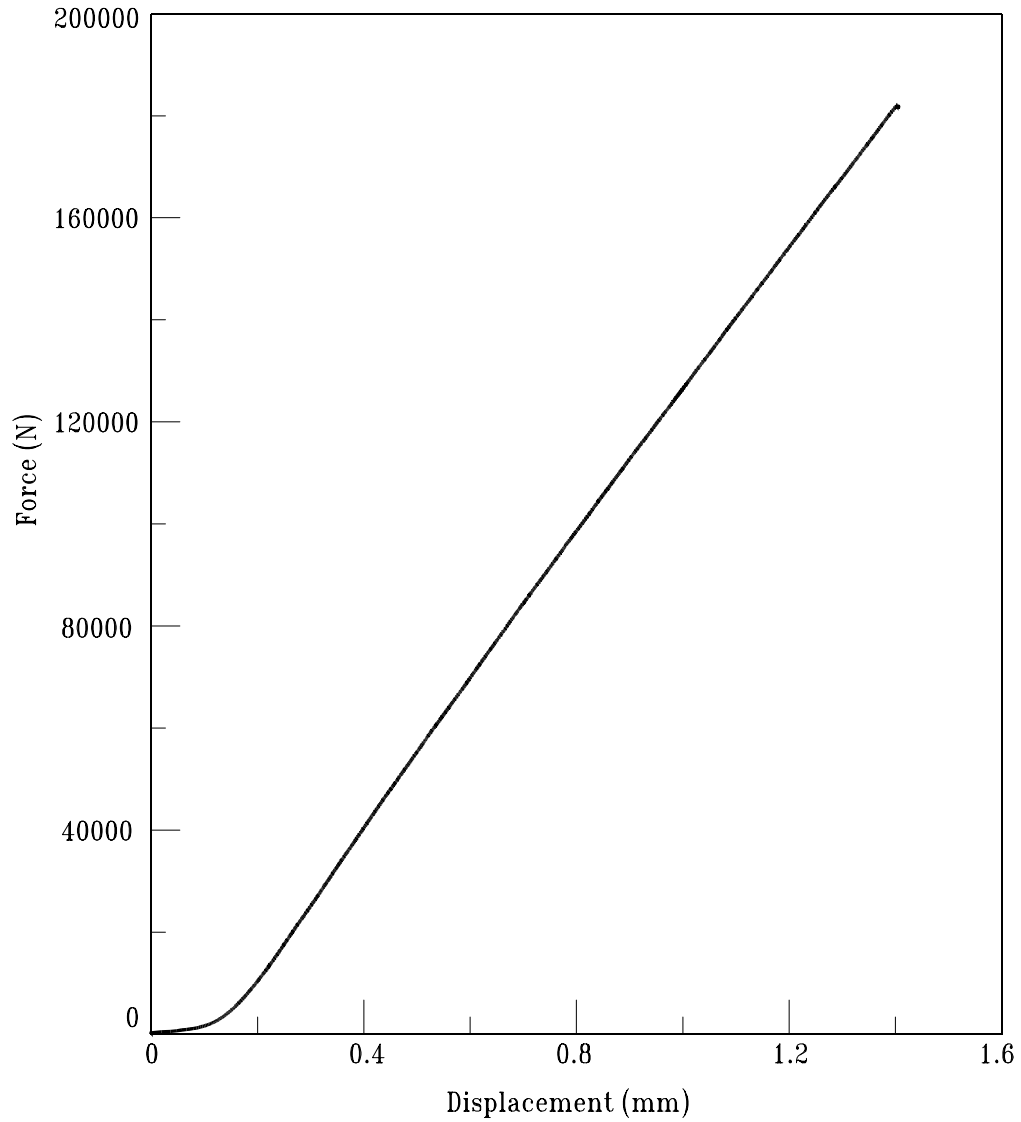
Figure 2.4 Type B - Hysteresis curve: 0.25 mm, 20 Hz



2nd static loading:

Static stiffness :	141700 kN/m
Deformation under applied load :	1.283 mm

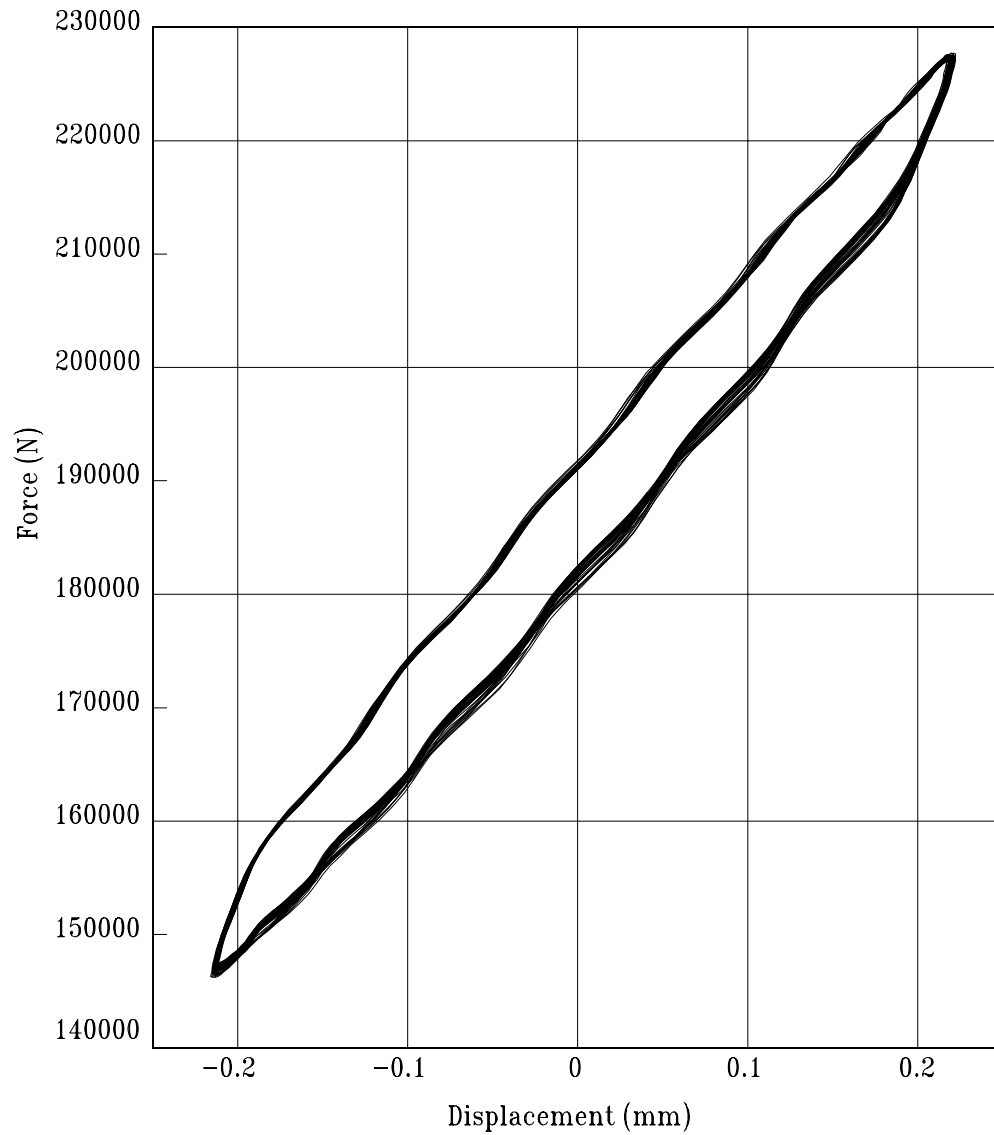
Figure 2.5 Type B - 2nd static loading curve



Dynamic loading 0.4 mm, 3 Hz:

	Displacement (mm)	Force (N)
max	0.222	227724
min	-0.216	146199
Dynamic stiffness : 186024 kN/m		

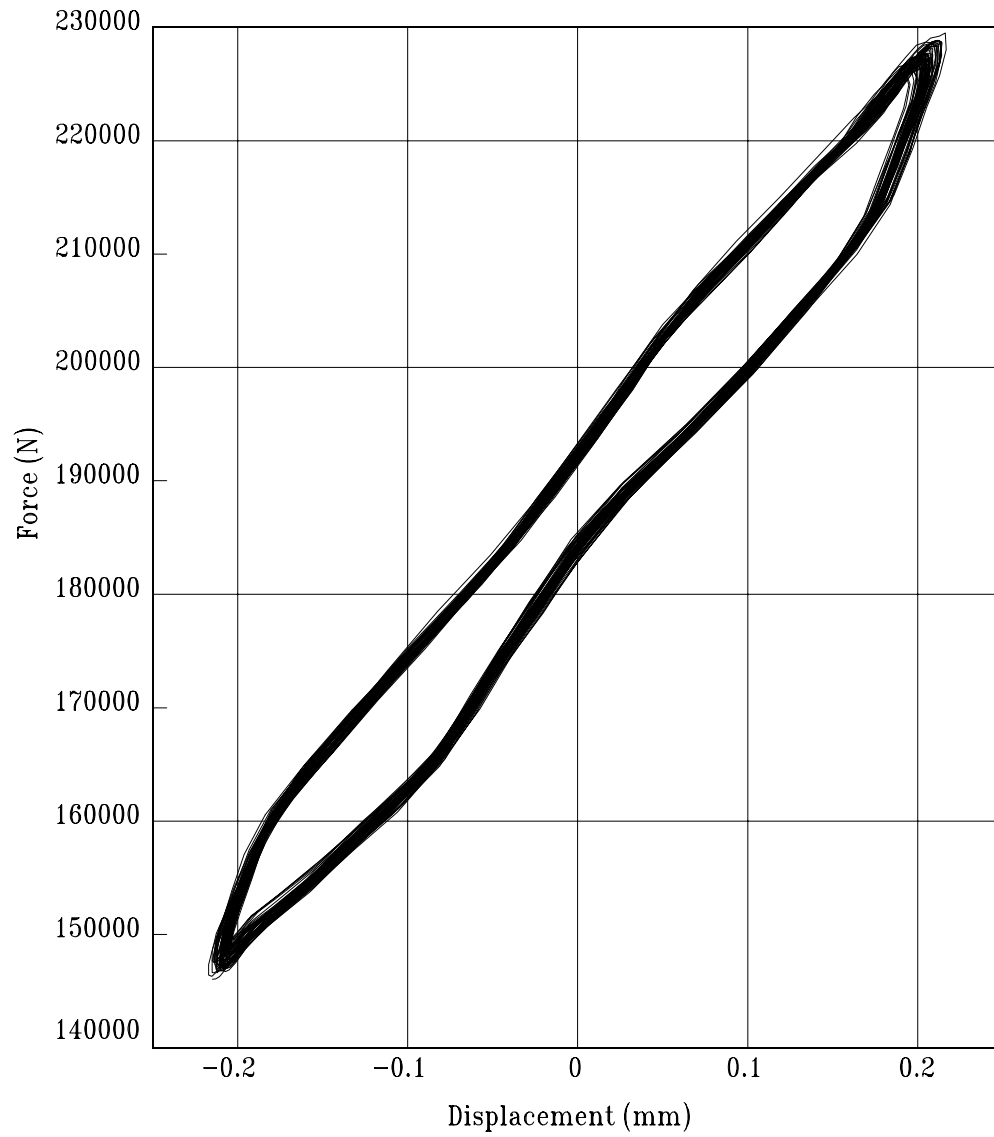
Figure 2.6 Type B - Hysteresis curve: 0.4 mm, 3 Hz



Dynamic loading 0.4 mm, 10 Hz:

	Displacement (mm)	Force (N)
max	0.217	229510
min	-0.217	146046
Dynamic stiffness : 192424 kN/m		

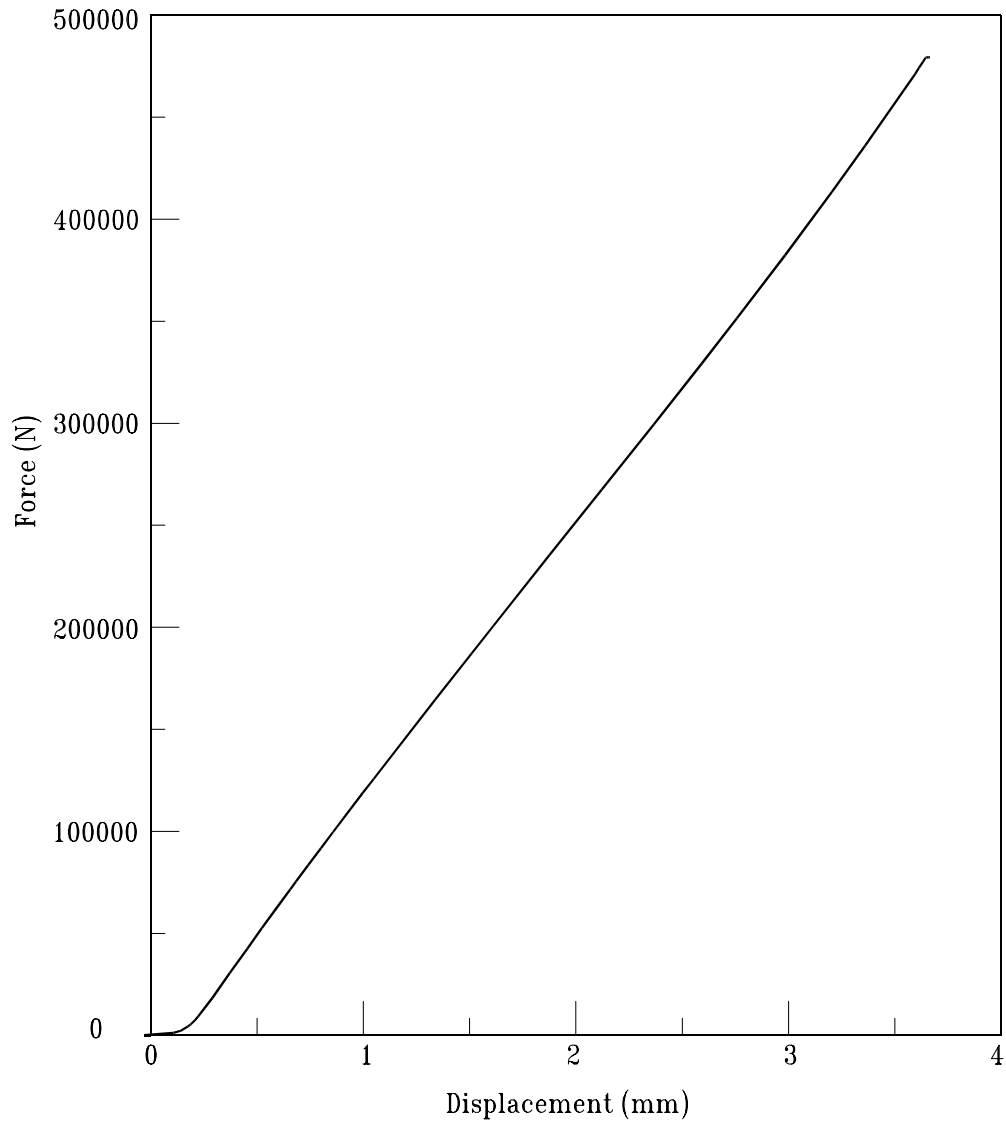
Figure 2.7 Type B - Hysteresis curve: 0.4 mm, 10 Hz



Final static loading:

Static stiffness :	134128 kN/m
Deformation under applied load :	3.572 mm

Figure 2.8 Type B - Final static loading curve



2.2 BEARING TYPE G

2.2.1 Summary

Test conditions:

- Bearing dimensions for Type G: 420 mm \times 420 mm \times 262 mm ($L \times l \times h$)
- Compression load for dynamic tests: 364 kN

Table 2.3 Static stiffnesses calculated for Type G

Test	Static stiffness (kN/m)
1 st static loading	65710
2 nd static loading	66001
Final static loading	63424

Table 2.4 Dynamic stiffnesses calculated for Type G

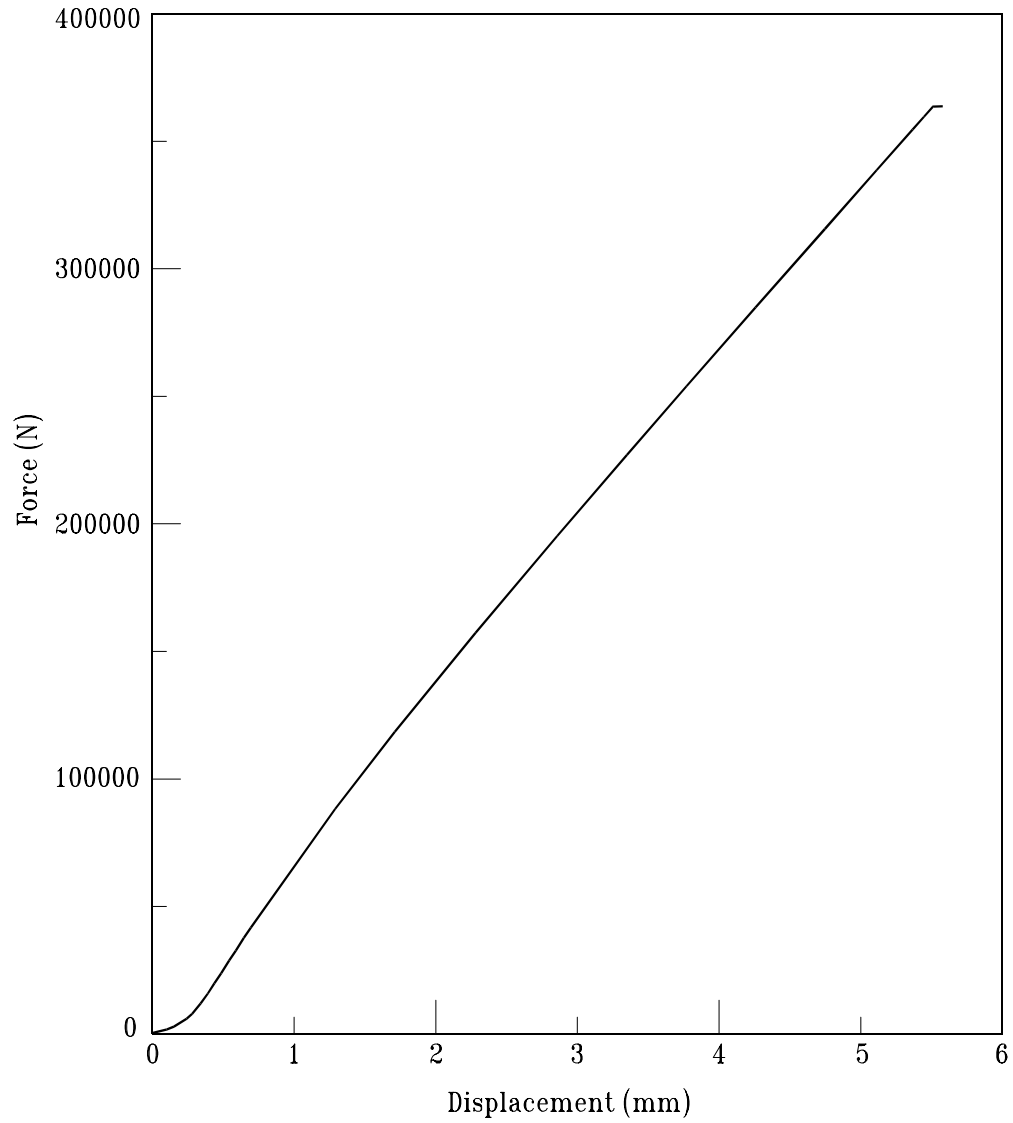
Excitation level (mm)	Frequency (Hz)	Dynamic stiffness (kN/m)	Error (%)
0.25	3	98571	16.5 -12.3
0.25	10	100900	15.6 -11.6
0.25	20	109937	15.0 -10.9
0.4	3	95734	9.8 -7.3
0.4	10	98647	9.9 -7.4

2.2.2 Hysteresis curves and values

1st static loading:

Static stiffness :	65710 kN/m
Deformation under applied load :	5.535 mm

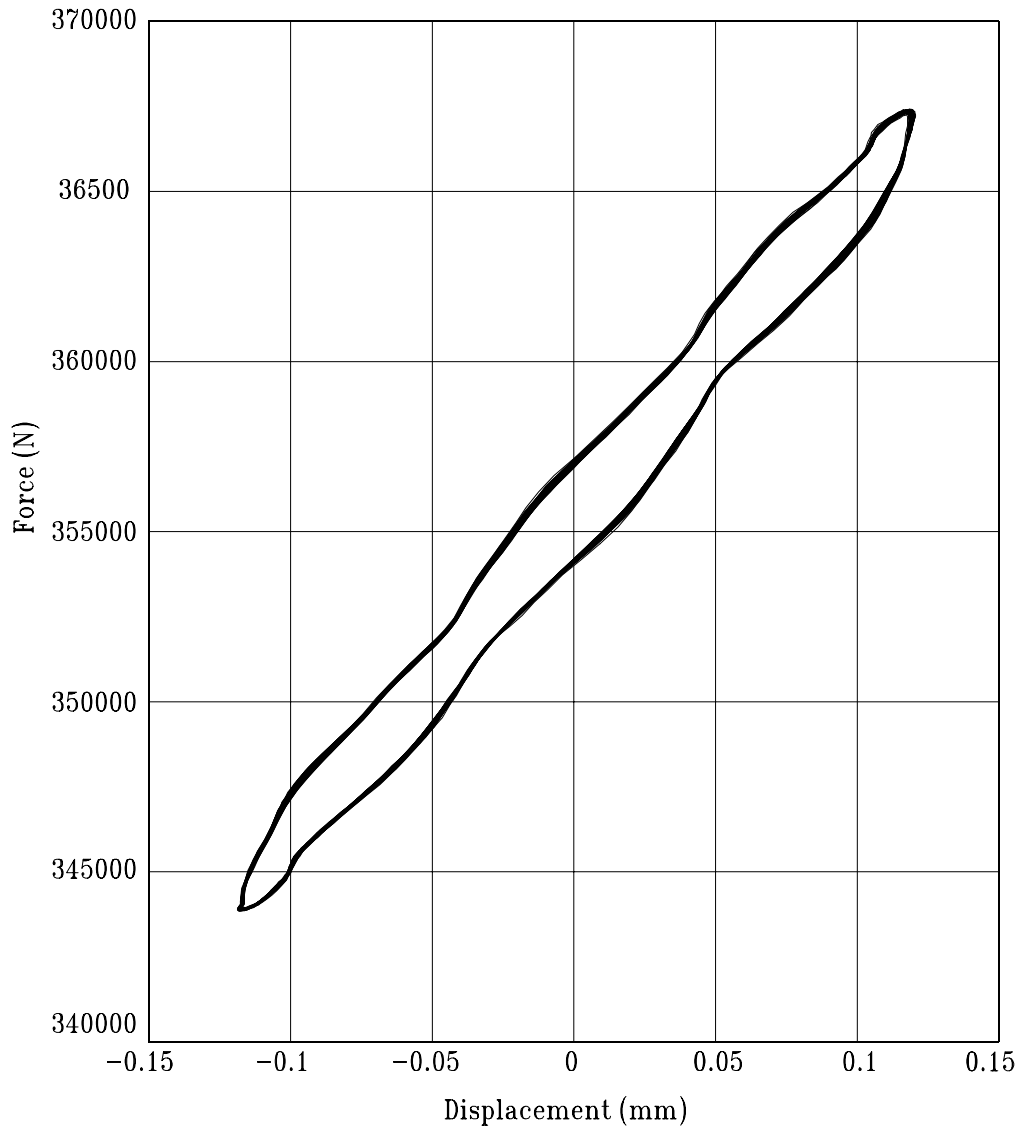
Figure 2.9 Type G - 1st static loading curve



Dynamic loading 0.25 mm, 3 Hz:

	Displacement (mm)	Force (N)
max	0.121	367421
min	-0.119	343838
Dynamic stiffness : 98571 kN/m		

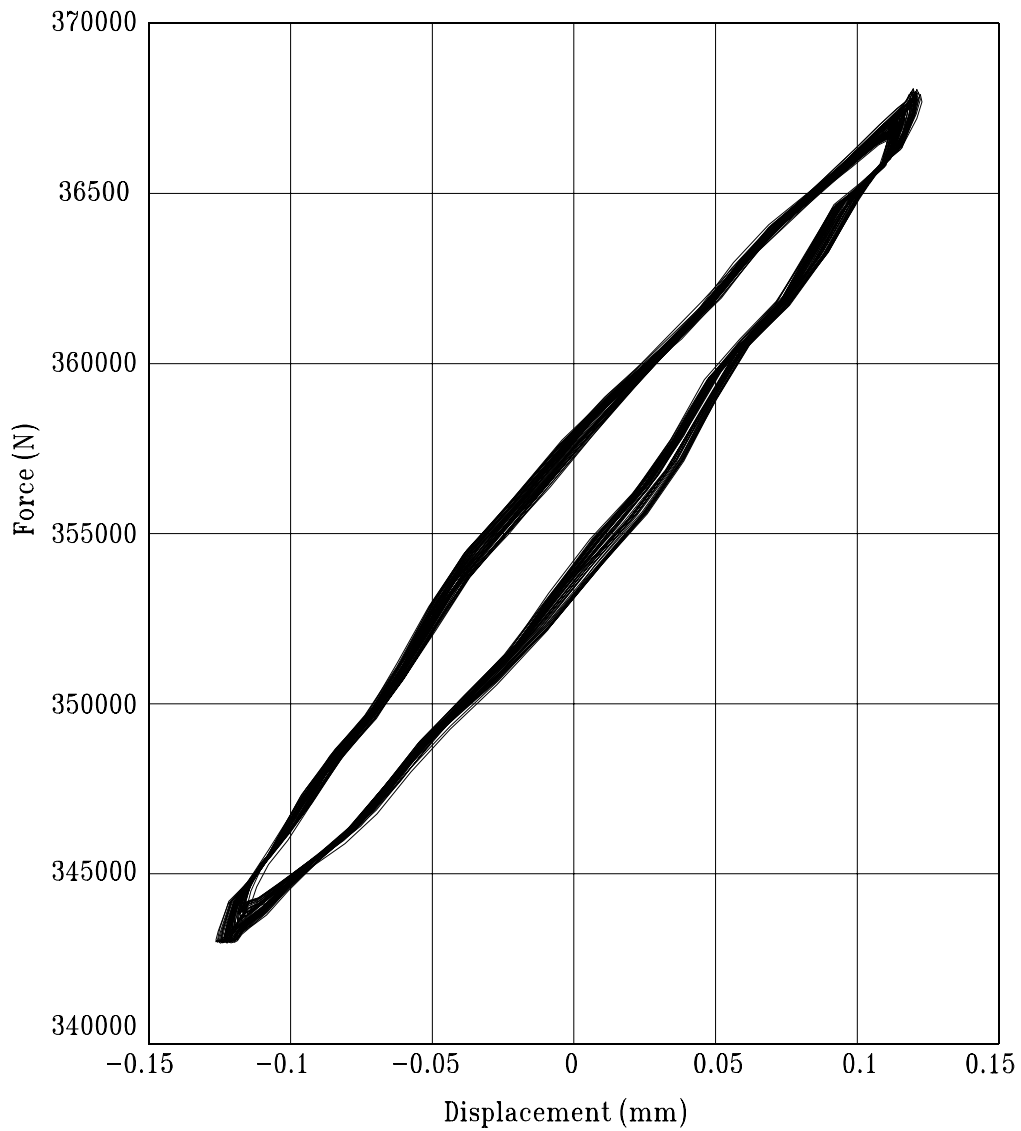
Figure 2.10 Type G - Hysteresis curve: 0.25 mm, 3 Hz



Dynamic loading 0.25 mm, 10 Hz:

	Displacement (mm)	Force (N)
max	0.123	368077
min	-0.126	342953
Dynamic stiffness : 100900 kN/m		

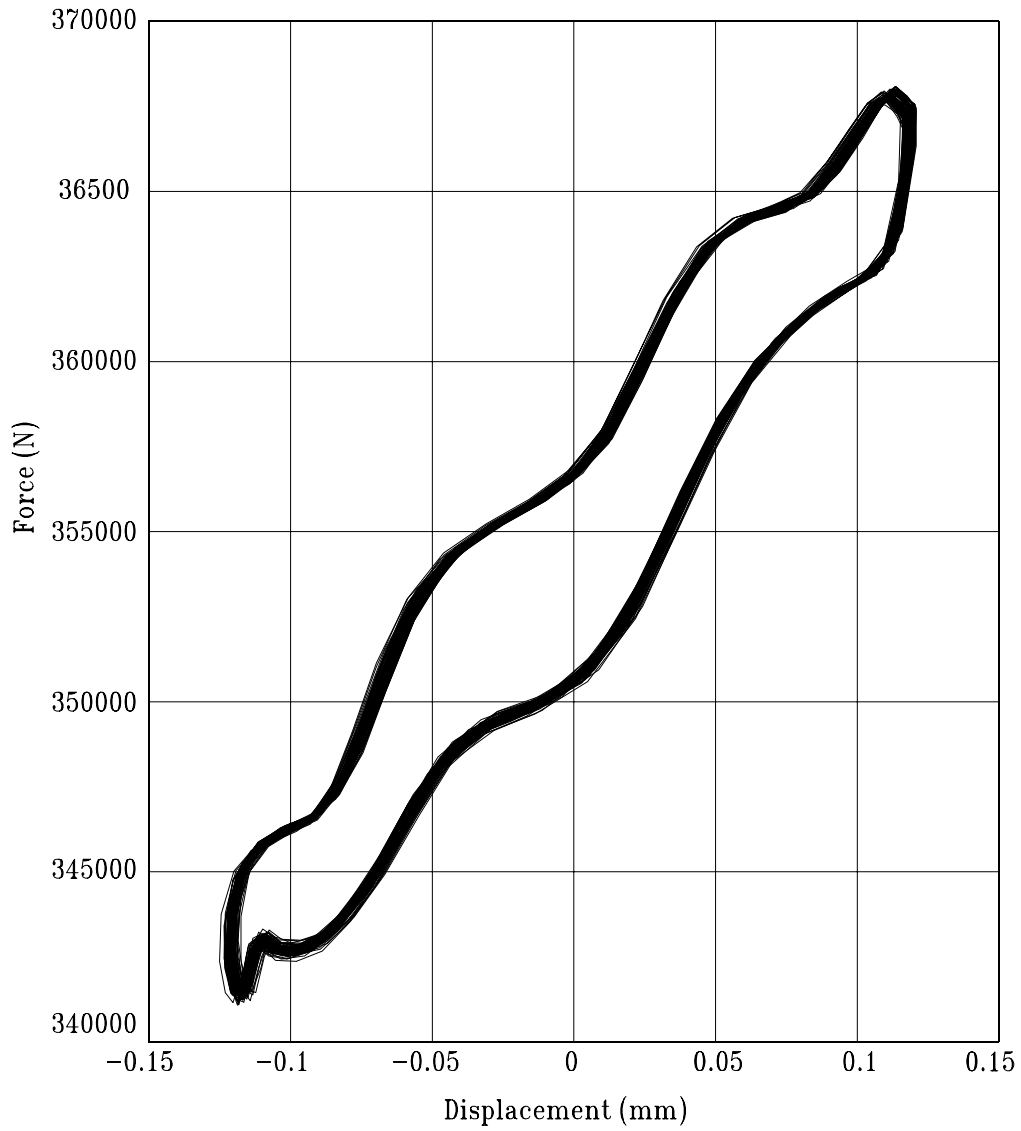
Figure 2.11 Type G - Hysteresis curve: 0.25 mm, 10 Hz



Dynamic loading 0.25 mm, 20 Hz:

	Displacement (mm)	Force (N)
max	0.121	368092
min	-0.125	341075
Dynamic stiffness : 109937 kN/m		

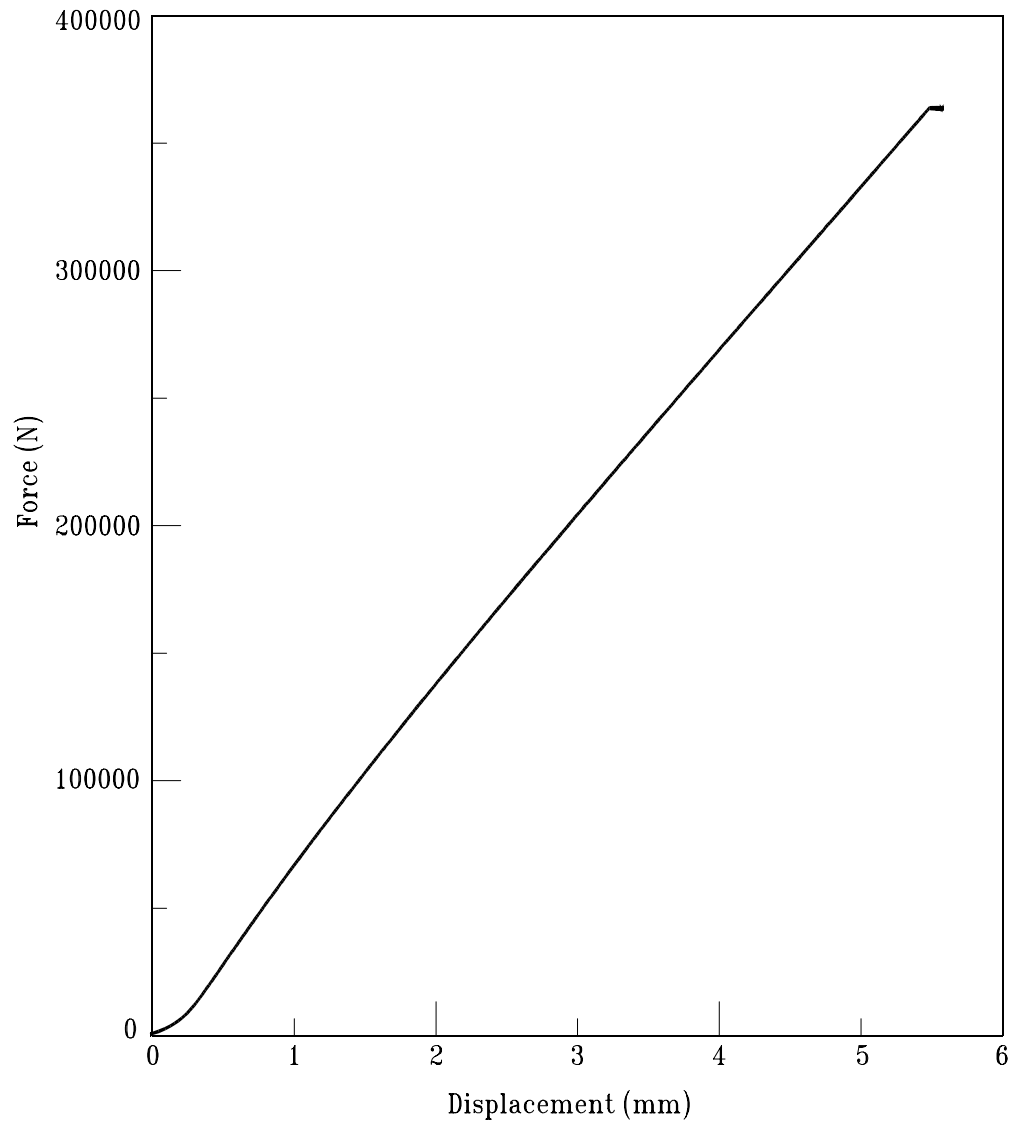
Figure 2.12 Type G - Hysteresis curve: 0.25 mm, 20 Hz



2nd static loading:

Static stiffness :	66001 kN/m
Deformation under applied load :	5.510 mm

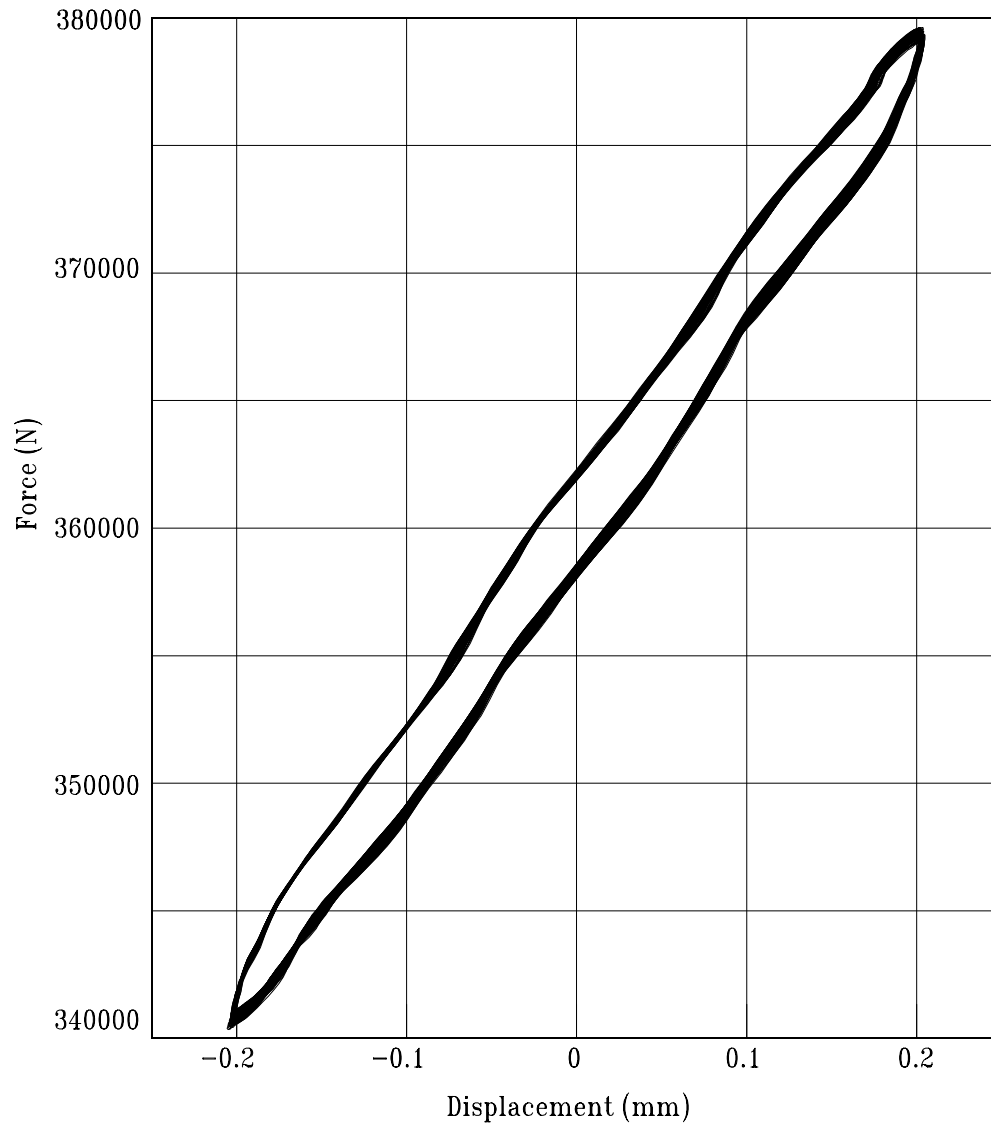
Figure 2.13 Type G - 2nd static loading curve



Dynamic loading 0.4 mm, 3 Hz:

	Displacement (mm)	Force (N)
max	0.205	379617
min	-0.206	340342
Dynamic stiffness : 95734 kN/m		

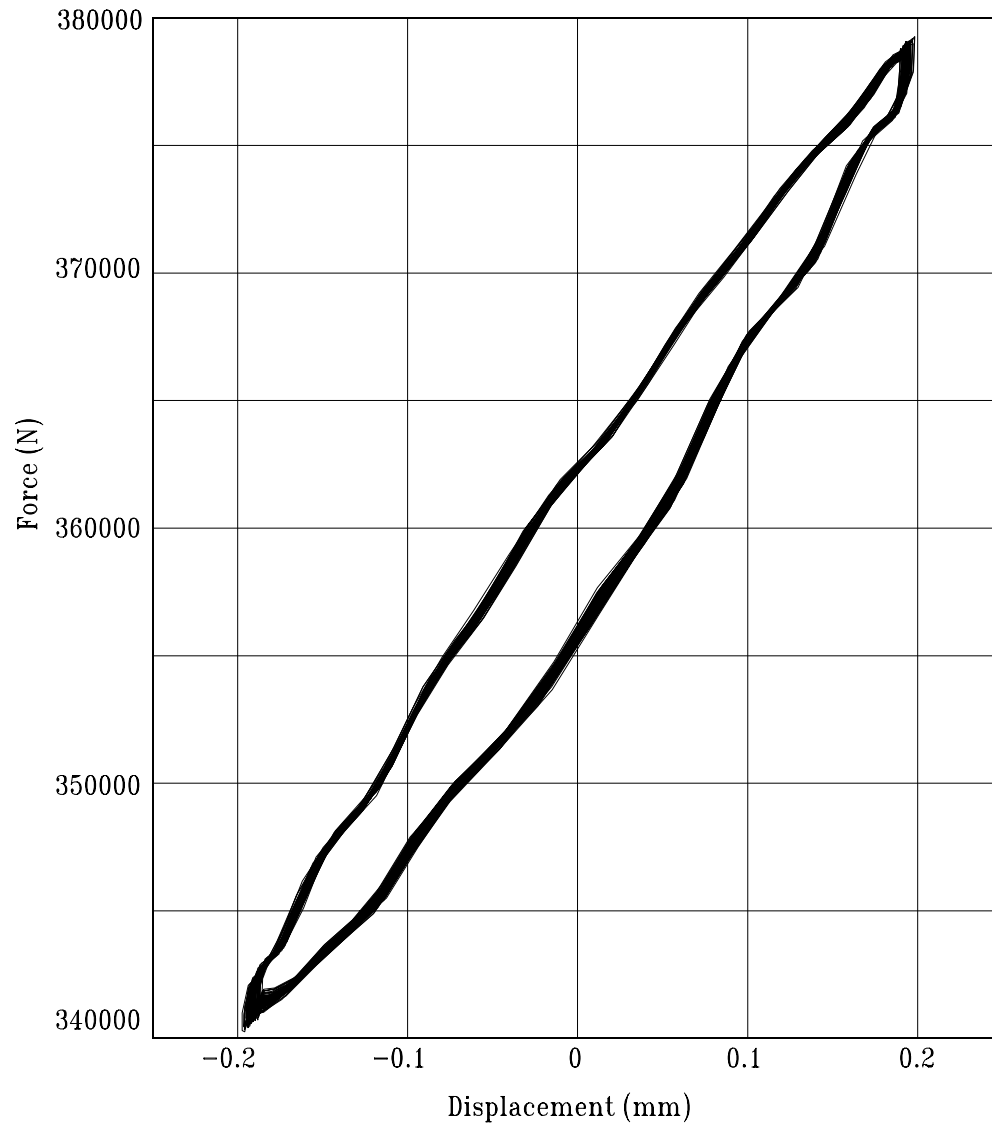
Figure 2.14 Type G - Hysteresis curve: 0.4 mm, 3 Hz



Dynamic loading 0.4 mm, 10 Hz:

	Displacement (mm)	Force (N)
max	0.198	379266
min	-0.197	340251
Dynamic stiffness : 98647 kN/m		

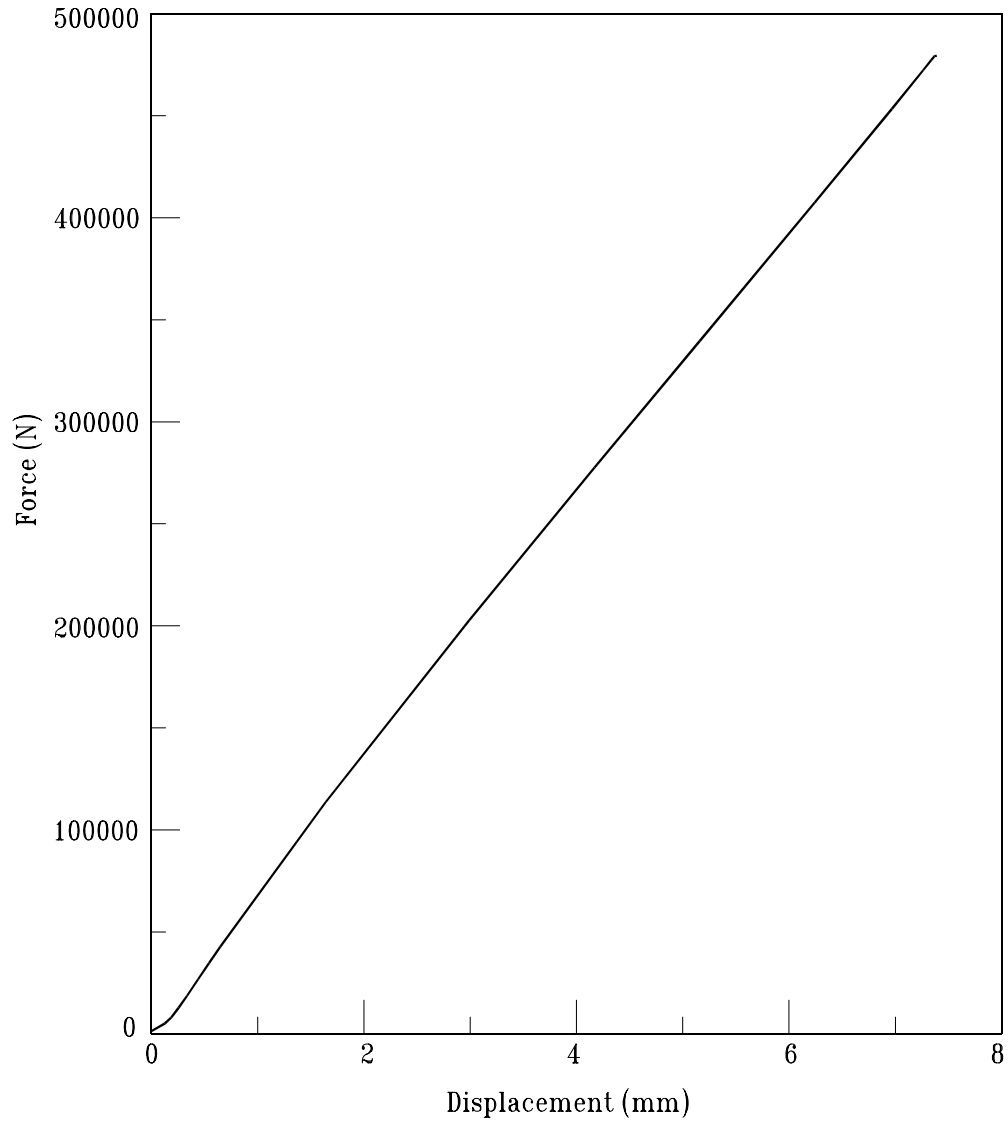
Figure 2.15 Type G - Hysteresis curve: 0.4 mm, 10 Hz



Final static loading:

Static stiffness :	63424 kN/m
Deformation under applied load :	7.558 mm

Figure 2.16 Type G - Final static loading curve



Conclusions

Experimental characterization tests for two natural rubber antivibration bearing specimen were conducted on January 18th 2008 and and February 19th 2008 by the CRGP (Centre de recherche en génie parasismique et en dynamique des structures) at the Université de Sherbrooke (Canada, QC). These tests were carried out for Produits HEVEA Inc., bearings supplier, and took place in the structures laboratory of the Civil Engineering Department.

Using a test protocol provided by Produits HEVEA Inc., the static and dynamic compression stiffnesses of the bearing devices were calculated using load and deformation data that were recorded during the tests. The results obtained during both tests indicates that the tests are repeatable.