Experimental And Numerical Modal Analysis Of A Concrete High Speed Train Railway Bridge

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Status

J. MAECK , G. DE ROECK, *Experimental and numerical modal analysis of a concrete high speed train railway bridge*, Proceedings of MCCI'2000 International Symposium on Modern Concrete Composites & Infrastructures, Volume 2, pp.61-68, Beijing, China, November 2000

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EXPERIMENTAL AND NUMERICAL MODAL ANALYSIS OF A CONCRETE HIGH SPEED TRAIN RAILWAY BRIDGE

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ABSTRACT

Train induced vibrations are a major environmental concern both in Europe and China. Besides the effect of vibrations due to passenger and freight trains and subways at relatively low speed, the study of the vibrational impact of high speed trains is of high interest. In Belgium, for example, new high speed train lines connect Brussels with Paris and London, while extensions to Amsterdam and Cologne are presently under construction. In China, this problem will become equally important in the near future, as a high speed train connection is planned between Beijing and Shanghai.
The partners in this research project are involved in the development of numerical models to predict traffic induced vibrations. The development, validation and practical use of these models rely on in situ vibration measurements. A preliminary measurement campaign was undertaken on a high speed train bridge, with sensors on the bridge as well as on the rails, to be able to get more insight in force transfer from train to construction.

Keywords: high speed train, dynamic testing, modal analysis

INTRODUCTION

The construction under consideration is a railway bridge for the high speed train between Paris and Brussels. The bridge is situated near the Belgian village Antoing, close to the Belgian-French border. The total bridge consists of successively five prestressed concrete bridges of each 50m span, a mixed steel-concrete bowstring bridge, which is built over a river, and a last 50m span concrete bridge. The bridge tests and simulations can be situated in a bilateral research program (BIL98/09) between the Belgian universities K.U. Leuven and V.U.Brussel, and the Northern Jiaotong University, Beijing, China. Aim of the program is to study the train-structure interaction and the vibrations induced in the environment.

FINITE ELEMENT MODEL

A complete modal analysis of the first 50 span bridge is used as starting point for the experimental survey.
From symmetry considerations only half a span is modeled in the finite element package Ansys [2]. Eight noded brick elements are used, three translational degrees of freedom at each node. The concrete is considered homogeneous, E-modulus 40,000 MPa, density 2500 kg/m^3. The bridge section is denoted in Figure 1. The stone material of the ballast is accounted for as extra mass (1500kg/m^3). The supports are considered fixed in vertical direction.

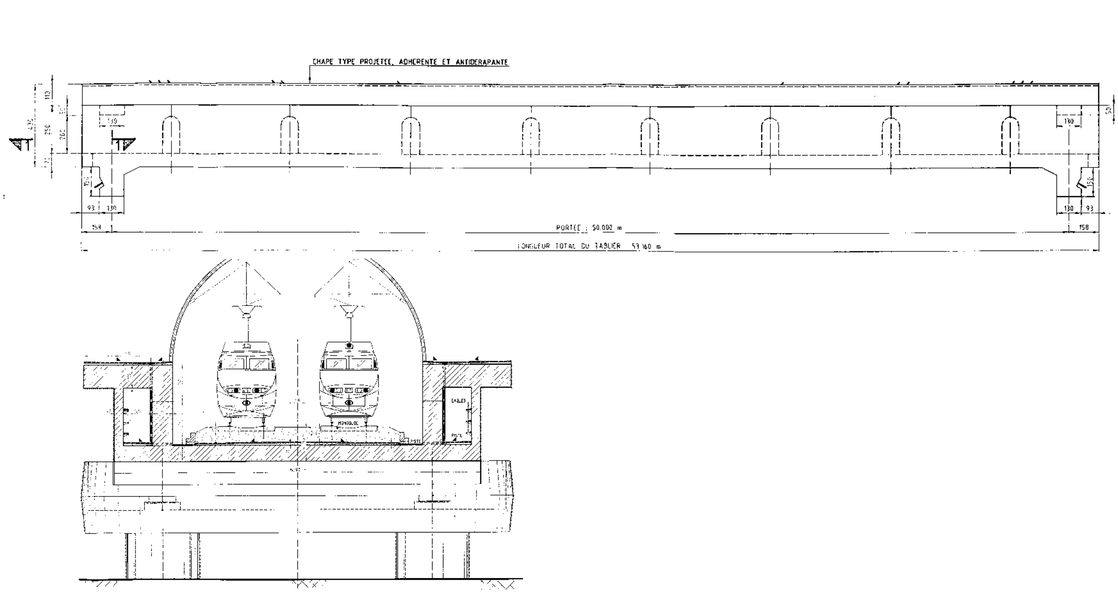


Figure 1 Elevation & cross section Antoing bridge

Figure 2 (a) Antoing bridge (b) Maintenance tunnel

Frequencies of all modes under 25 Hz are summarized in Table 1.

Symmetrical modes	**eigenfrequency (Hz)**	**characterization**
B1	3.08	first bending
T1	3.88	first torsional
S1	6.55	first bending of cross section
B3	14.57	second symmatrical bending
S2	14.92	second bending of cross section
Anti-symmetrical modes		
B2	9.32	first anti-symmetrical bending
T2	11.17	second torsional
S3	12.67	anti-symmetrical, first bending of cross section
B4	18.44	second anti-symmetrical bending

Table 1 Eigenfrequencies

An overview of the eigenmodes is given in the next plots.

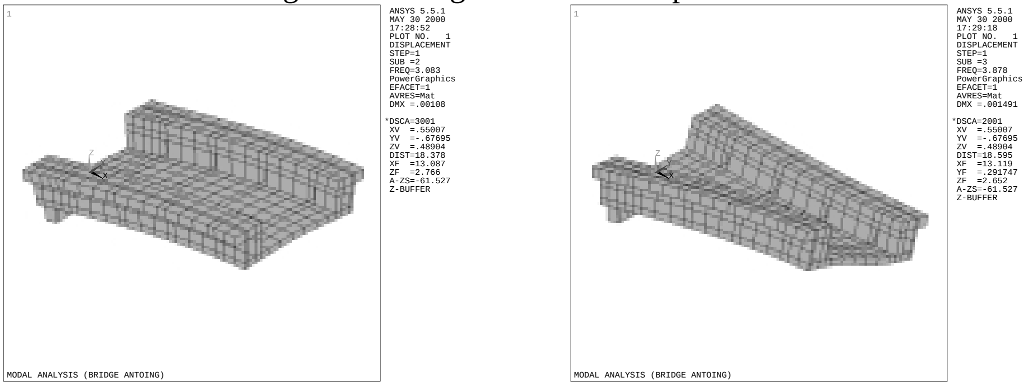


Figure 3 T1 & B1

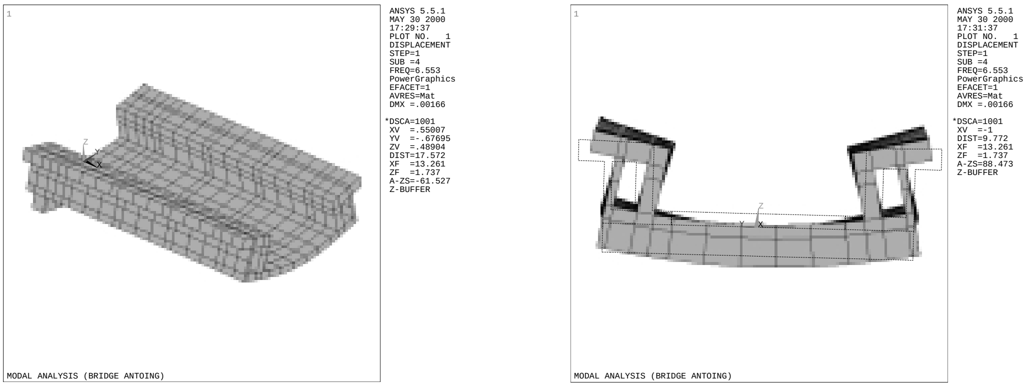


Figure 4 S1 (axonometric and front view)

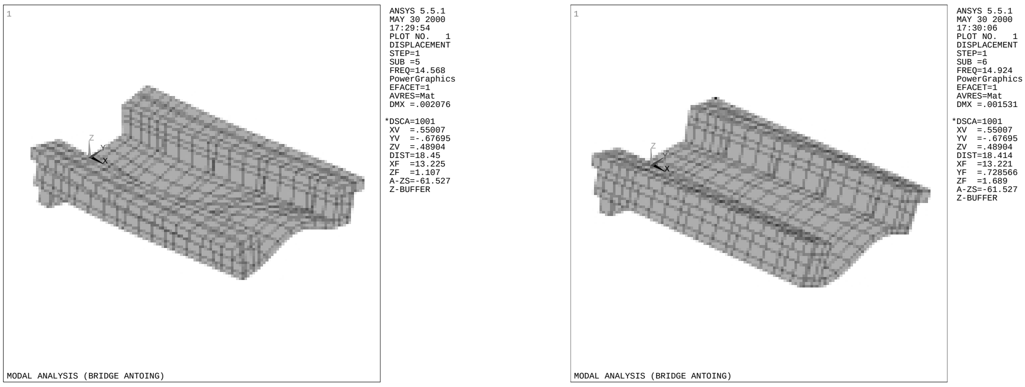


Figure 5 B3 & S2

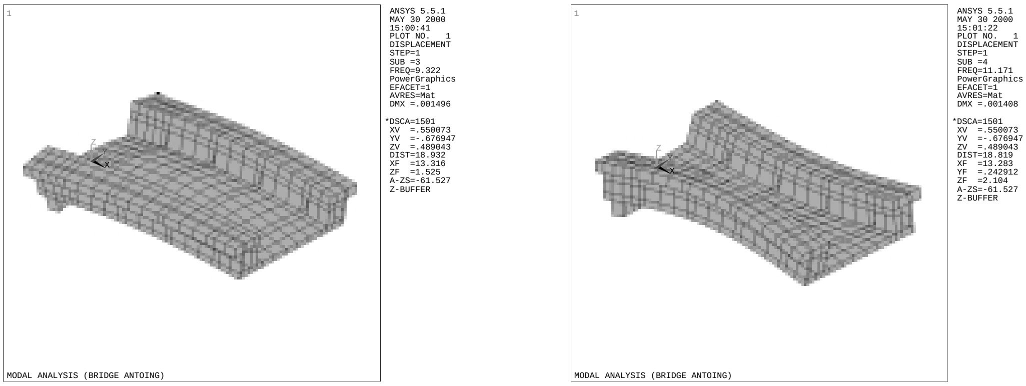


Figure 6 B2 & T2

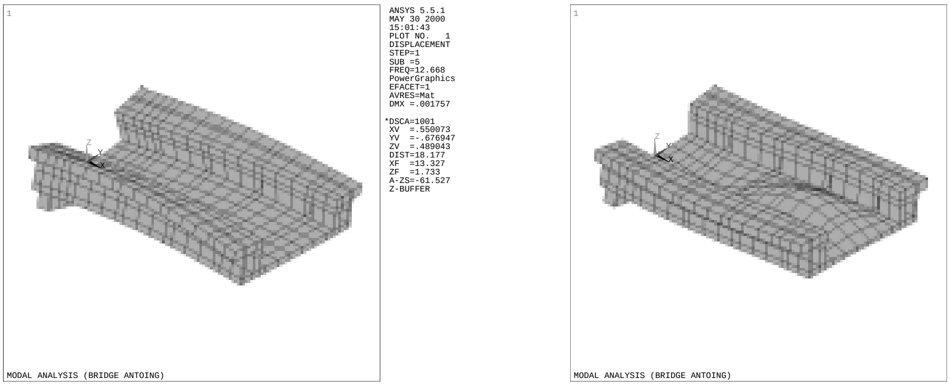


Figure 7 S3 & B4

EXPERIMENTAL TEST PROCEDURE

The measurement campaign is focused on the bridge response to ambient vibration. Excitation of the bridge is due to train passages primarily and to wind load, road traffic (underneath bridge) and micro-tremors.

The experimental data to be measured on the bridge are accelerations, strains and a deflection.
The bridge span is divided in 12 equidistant zones. A total of 29 vertical, 4 transversal and 2 longitudinal accelerations, 18 strains and 1 vertical deflection are measured.
At the lower side of the girder, at the mid-section, two rosettes of resistance strain gauges are glued , at the center and at the location under one of the railway tracks, in order to investigate the strain changes during train passages. At the same location of one of the strain rosettes, the vertical deflection at one point of the bridge girder is measured with a LVDT. Also at the same location, the acceleration is measured.

In order to measure the train induced interaction forces, strain gauges are glued to both vertical sides of two rails of one track, again in rosette formation.
The sensor locations are indicated in Figure 8. Each sensor location has a unique number, A denotes acceleration measurement, S strain gauge measurement and D deflection measurement. Measurement direction is indicated by x, y or z (x longitudinal, y transverse, z vertical). Three reference accelerometers are used (A3z, A4z, A4y).

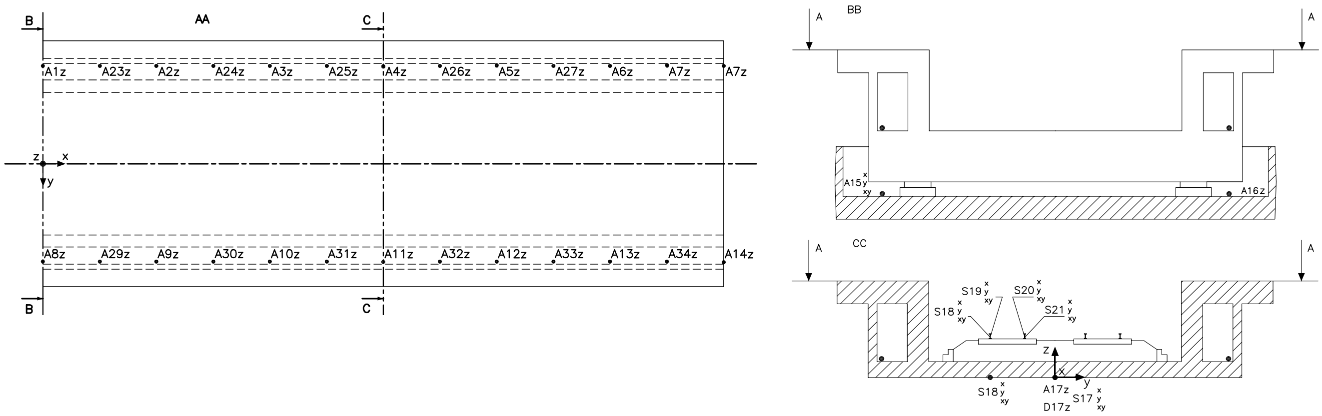


Figure 8 Sensor locations

For each set-up, three train passages are measured at sampling frequency 5000 Hz, 240k samples (49sec); reference A3z is used as trigger, with pretrigger of 6sec.
Measurement acquisition hardware equipment (portable PC, KEMO anti aliasing filter and amplifier, DAT recorder) is installed at the transverse maintenance tunnel between the 1st and 2nd span.

Figure 9 (a) Acquisition equipment (b) Strain gauge rosette on rail

The LVDT at the girder is installed on a stiff cable stayed antenna construction.

EXPERIMENTAL RESULTS

Figure 10 shows the time signal and frequency contents of a typical acceleration data series of one of the accelerometers (A3z) placed in the maintenance tunnel at the France to Brussels side. Two trains are passing, a long train in direction Brussels , a short train in direction France. High frequency contents is noticed during train passage.

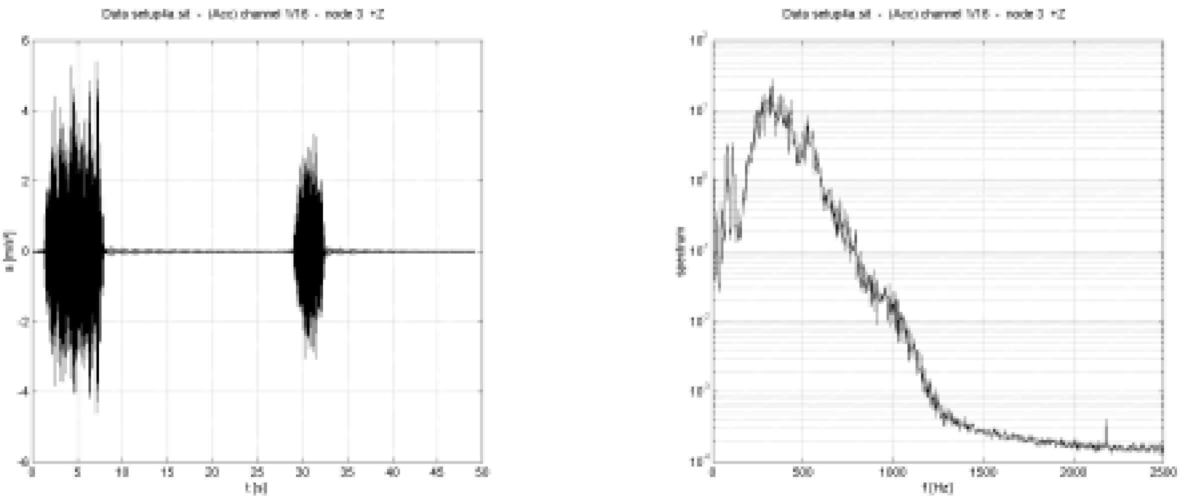


Figure 10 Time signal & spectrum (1^{st} passage) A3z

The vertical displacement measured by the LVDT on the stiff antenna, at the center of the span is shown in Figure 11. Maximum deflection is 1500µm. From the free vibration after passage the first eigenfrequency at 3.12Hz is clearly detectable. Higher eigenfrequencies are more difficult to detect as displacement spectrum is decreasing quickly and many of the higher modes have zero displacement at the sensor location.

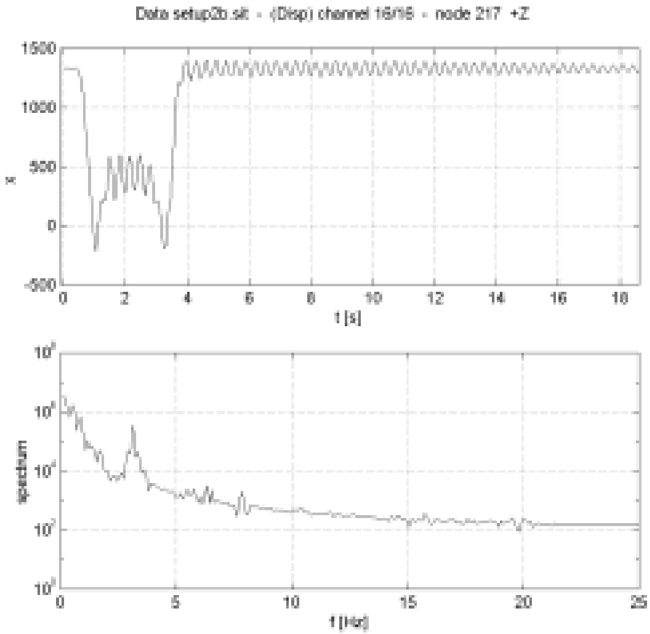
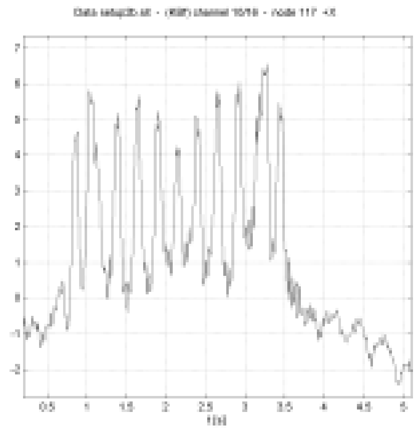


Figure 11 LVDT signal

The strain gauge signal (S17x) is denoted in Figure 12. Although the strain level reaches a low peak value of 6µS the 13 boogie passages are clearly detectable. Boogie 2&3 and 11&12 are close resulting in double peak in the time signal. From this timesignal the train speed is estimated at 265km/h.



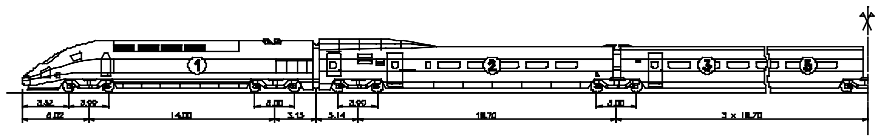


Figure 12 (a) Strain gauge on bridge (b) High speed train composition

DATA PROCESSING

The stochastic subspace identification technique is used to extract the modal characteristics from the data [3]. The technique has been implemented (SPICE [4]) in the MATLAB environment [5]. Data is decimated with a factor 100 (low pass filtering at 50Hz) and limited to free vibration after train passage, to result in frequencies and damping ratios of Table 2.

mode	eigenfrequency (Hz)	damping ratio (%)	characterization
B1	3.12	0.55	first bending
T1	3.85	0.95	first torsional
S1	6.59	1.2	
B2	8.54	1.3	first anti-symmetrical bending
T2	10.34	2.0	second torsional
S3	11.99	0.98	
B3	18.56	1.1	second symmetrical bending
B4	19.28	0.56	

Table 2 Experimental modal characteristics

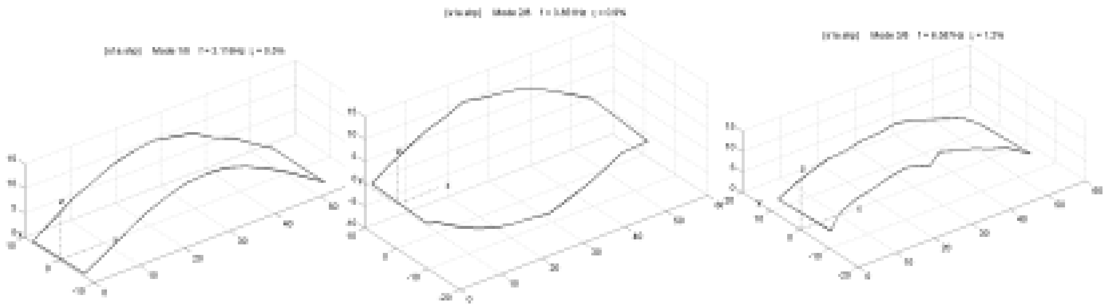


Figure 13 Experimental modes 1,2,3

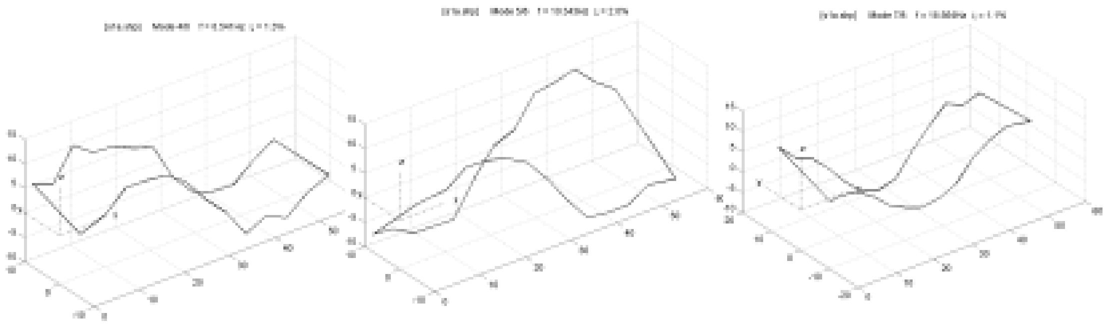


Figure 14 Experimental modes 4,5,7

CONCLUSIONS

A full modal analysis was carried out on a prestressed concrete bridge for the high speed train, using the acceleration data captured in the maintenance tunnels. The experimentally determined eigenfrequencies showed a good correspondence with the numerical results from a finite element model, as far as the lowest eigenfrequencies are concerned. For further agreement between experiments and FE model, updating of E-modulus and boundary condition characteristics is now being carried out.
The measured strains on the concrete and the deflection gave good data, provided that resistance strain gauges and LVDT have their limitations in maximum frequency range and dynamic resolution.
However strain measurement on the rails was disturbed by the presence of high current short circuit between rails and during high speed train passage. Strain signals denoted a lot of electrical noise (50Hz and multiples). Solutions for this phenomenon could be the use of special guarded gauges or optical fiber technology, to avoid electromagnetic interference.

It was suggested also to use more LVDT in the next measurement campaign, also in transversal direction. Focus will be then on the quantification of transferred forces from high speed train to structure.

ACKNOWLEDGEMENT

The research has been carried out in the framework of the bilateral research project 'Traffic induced vibrations in the built environment' BIL98/09 with a financial contribution by the Ministry of the Flemish Community.

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