EFFECT OF THE TRAFFIC CAUSED VIBRATIONS ON THE EARTHQUAKE RESISTANCE OF MASONRY STRUCTURES*

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ABSTRACT

The traffic is harmful not only because of the noise pollution but it also causes vibration in buildings. The spreading waves induce vibration in the foundations of buildings. The dynamic factor depends on the mass and the speed of vehicles. The masonry walls crack, plastering falls down, fractures and perilous strains occur. The almost permanent vibration causes the accumulation of damages in buildings.

Key-words: traffic caused vibration, resistance of masonry, wave propagation

REZUMAT

Traficul este dăunător nu numai datorită poluării sonore ci, de asemenea, datorită faptului că produce vibrații în clădiri. Undele generate de trafic induc vibrații în fundațiile clădirilor. Factorul dinamic depinde de masa şi de viteza vehiculelor. Pereții de zidărie fisurează, tencuiala cade, se produc fisuri şi deformații periculoase. Vibrația aproape permanentă determină acumularea de avarii în clădiri.

Cuvinte-cheie: vibrații datorate traficului, rezistența zidăriei, propagarea undelor

1. FLEXIBLE WAVES

Traffic (road, urban, railway, rail-guided urban) induces the buildings in forms of support's vibration. This effect is especially typical for the buildings along the narrow streets in cities; it is shown by the sensors mounted on the buildings. Processing of the vibrations caused by traffic recently has broadened the initial research results.

Vehicles induce waves on the upper surface of the ground with their movements. These waves spread in form of flexible waves, reflect on the stratum, break and superimpose with the direct waves spreading on the surface and so generate movement in the foundation of the building. The spreading velocity depends on the axial deformation modulus and shear modulus and of the stratification. The dynamic force causing the excitation is determined by the mass of moving object, the ratio between its minimal and maximal values depends on the speed of vehicle; the dynamic factor depends on the suspension of the vehicle.

For studying the density of the response spectrum of a building the peaks in the natural vibration quasi prove the inducing effect of traffic so the building is sensitive to the frequencies corresponding to its natural vibration. Time deviations can be found because of the accumulation of damages.

On the effect of a force F operating in a point of the surface of ground or road or path deformations occurs in the soil. The deformations in the soil spread in longitudinal (P) and transversal (S) waves. On the surface of the ground – rather far from the excitation – an R wave forms. Spreading of the flexible waves in the strata of the ground leads to forming of L waves. In the ground as a flexible space the spreading velocity of the waves depends of the flexibility, deformation and shear modulus of the relevant stratus as well as of the typical Poisson factor. The traffic caused waves in the built environment are as background noises, the vehicles passing near to the studied building make local peaks in the response spectrum.

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It is a fact supported by measurements that the excitations generated by the vehicle of the same type, mass and motional speed lead to different responses in buildings of similar mass and rigidity because of the stratification of the soil.

On the basis of the performed measurements and the literature:

- The traffic caused vibrations initially (at a low number of repetition) cause invisible damages.
- The invisible damages are demonstrated at first only by the modification of the natural vibration.
- The further repetitions cause microscopic cracks in the mortar.
- The microscopic cracks cause slacking of the mortar which leads to the cracked state of the walls.

Table Nr. 1

Storeys	Class of execution							
	A	B	C	D	E	F	G	H
1	6	5	8	4	6	2	1	-
2	-	1	3	1	2	5	6	-
3	-	1	1	2	4	3	5	-
4N		-	1	3	3	7	1	-
5		-	1	2	2	7	2	1
Σ	6	7	14	12	17	24	15	1

A – before 1940 brick layer -;
B – before 1940 master -;
C – between 1940 – 1950 master -;
D – between 1950 – 1976 builder master -;
E – between 1976 – 1981 architect -;
F – between 1981 – 2000 architect-engineer -;
G – after 2000 non-dimensioned -;
H – after 2000 dimensioned structures.

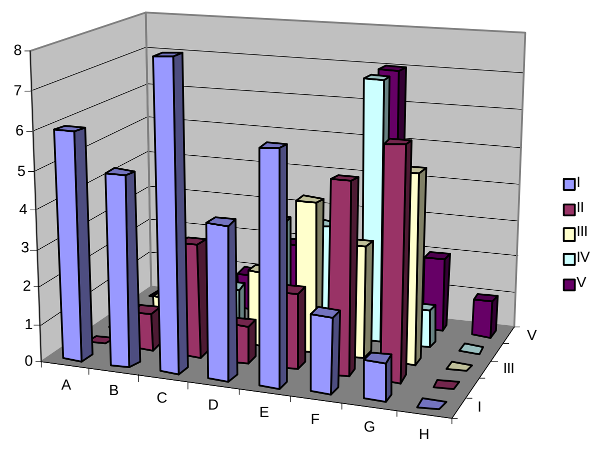

Fig. 1. Types of structures

- The cracks result in the increase in the natural vibration and the reduction of the bearing capacity of the building.
- Reduction in the bearing capacity endangers the earthquake resistance of the given building.

An overall programme should be made beginning from the examination to the measurement of the modification of the natural vibration. Wide processing of the results leads to a simple, easy to use evaluating procedure.

2. MEASUREMENTS

We had no laboratory measurements; we processed only site vibration measurements. The traffic caused vibrations were measured on 32 one-storey, 18 two-storey. 16 three-storey, 15 four-storey and 15 five-storey houses of the 96 buildings and the damages of the buildings were examined on them. Because we didn't know under which standards they had been built, it was determined on the basis of their ages. So the basic mode was calculated from the determined building structure and the mass. The reduction was determined from the effective measured value and the calculated one. Table Nr. 1. Fig. Nr. 1.

3. STRENGTH OF WALL AND REPETITION

Within the zone of the natural vibration the damage as accumulating effect was examined. Traffic is a repetitive load; there is a quasi excitation state to which peaks are made by the direct traffic front. Dynamic effect means that a wall has a maximal and a minimal σ value relating to the basic value σ_0.

In case of masonry structures a correction factor is determined as a function of the repetition number. [18] Under the effect of the cyclic load the decrease in the compressive strength of the masonry structure is lower than that of the tensile or shear strength.

$$\Delta fc = m_c \cdot fc; \;\; \Delta ft = m_t \cdot ft; \quad \Delta f\tau = m_\tau \cdot f\tau \tag{1}$$

It means that relating to the static load the dynamic effect of the traffic caused excitation derives not only from the dynamic additional load but the bearing capacity, which decreases because of "fatigue". It causes cleavage, and its change in time increases this effect.

Table Nr. 2

IM = r	Reduction factor m_c of compression							
	– 0,40	– 0,20	0,00	0,20	0,40	0,60	0,80	1,00
10^3	0,01	0,20	0,50	0,77	0,87	0,95	0,98	0,99
5×10^3	0,00	0,16	0,47	0,72	0,82	0,92	0,97	0,98
5×10^4	0,00	0,13	0,44	0,69	0,79	0,87	0,94	0,96
5×10^5	0,00	0,02	0,25	0,64	0,74	0,81	0,89	0,93
5×10^6	0,00	0,00	0,19	0,60	0,70	0,78	0,86	0,90
5×10^7	0,00	0,00	0,14	0,53	0,63	0,71	0,79	0,87
5×10^8	0,00	0,00	0,07	0,46	0,56	0,63	0,74	0,83
5×10^9	0,00	0,00	0,01	0,38	0,48	0,55	0,69	0,80

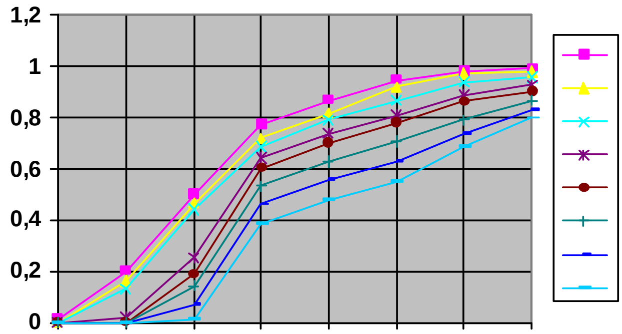

Fig. 2. Reduction factor m_c of compression

Table Nr. 3

IM = r	Reduction factor m_t of tension							
	-0,4	-0,2	0,00	0,2	0,4	0,6	0,8	1,0
10^3	0,09	0,15	0,23	0,39	0,57	0,75	0,89	1,00
5×10^3	0,07	0,09	0,18	0,34	0,52	0,72	0,86	0,99
5×10^4	0,01	0,06	0,14	0,30	0,50	0,65	0,79	0,95
5×10^5	0,00	0,03	0,10	0,26	0,45	0,60	0,72	0,90
5×10^6	0,00	0,01	0,06	0,19	0,37	0,53	0,64	0,85
5×10^7		0,00	0,01	0,09	0,25	0,40	0,52	0,75
5×10^8		0,00	0,00	0,02	0,17	0,33	0,44	0,65
5×10^9		0,00	0,00	0,00	0,10	0,25	0,39	0,60

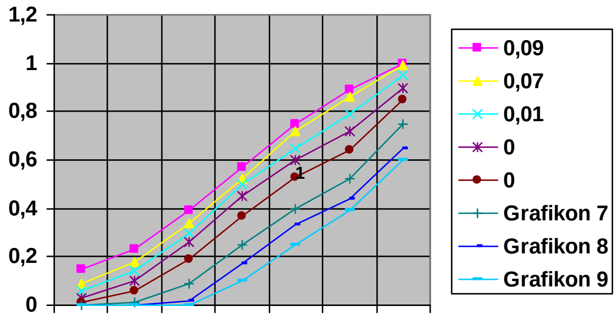

Fig. 3. Reduction factor m_t of compression

Table Nr. 4

IM = r	Reduction factor m_τ shear							
	– 0,4	– 0,2	0,00	0,20	0,40	0,60	0,80	1,00
10^3	0,13	0,26	0,44	0,54	0,74	0,86	0,94	1,00
5×10^3	0,11	0,23	0,38	0,51	0,71	0,83	0,93	0,99
5×10^4	0,07	0,12	0,35	0,48	0,67	0,80	0,90	0,96
5×10^5	0,03	0,09	0,28	0,44	0,61	0,76	0,88	0,94
5×10^6	0,01	0,06	0,16	0,34	0,54	0,69	0,84	0,92
5×10^7	0,00	0,04	0,11	0,27	0,46	0,64	0,79	0,87
5×10^8	0,00	0,01	0,06	0,16	0,36	0,53	0,68	0,82
5×10^9	0,00	0,00	0,02	0,12	0,30	0,47	0,62	0,76

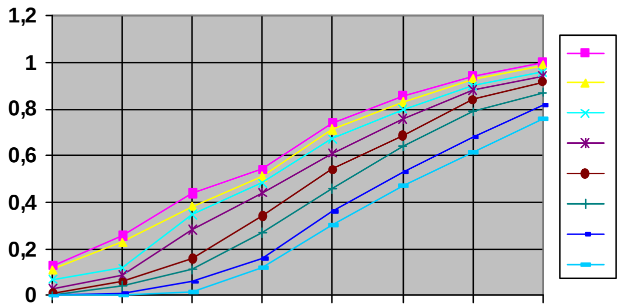

Fig. 4. Reduction factor m_τ of shear

4. STRUCTURAL CHANGES

The repetition led to cleavage, its process shows that the cracks modify the natural vibrations of the structure (table nr. 5).

In our paper we searched for the answer to the question that starting from the "original" vibration period of the examined buildings what reduction in bearing capacity was caused by the cleavage derived from traffic. The acceleration spectrum was

Table Nr. 5

Number of stories	Own vibration T [s]	ΔT [%]				
		I.	II.	III.	IV.	V.
1	$\leq 0{,}05$	10	21	31	42	53
2	$0{,}051 \leq T \leq 0{,}10$	8	17	25	33	42
3	$0{,}101 \leq T \leq 0{,}15$	6	12	19	25	31
4	$0{,}151 \leq T \leq 0{,}20$	4	8	12	16	20
5	$0{,}201 \leq T \leq 0{,}25$	2	4	5	7	9

calculated according to the standards MI-04.133-81 -, HSM - and MSZ EN 1998-1-1:2006.

$$S_a = 0{,}067 \cdot \frac{1}{T} \cdot g\,[\mathrm{m/s^2}]; \quad S_{a,\max} = 0{,}0223 \cdot g\,[\mathrm{m/s^2}] \tag{2}$$

$$S_a = 0{,}064 \cdot \frac{1}{T} \cdot g\,[\mathrm{m/s^2}];$$

$$S_{a,\max} = 0{,}02563 \cdot g\,[\mathrm{m/s^2}] \tag{3}$$

$$S_a = 0{,}15753 \cdot \left[\frac{2}{3} + \frac{T}{0{,}12}\right] \cdot g\,[\mathrm{m/s^2}];$$

$$S_{a,\max} = 0{,}26255 \cdot g\,[\mathrm{m/s^2}] \tag{4}$$

Reduction in bearing capacity caused by damages is divided into five classes: damages causing I. insignificant; II. significant; III. moderate; IV. a bit heavy; V. heavy reduction in bearing capacity. The construction of the building is significant (e.g. the incline crack - damage forming in the pillar between two bay widths in the external first floor walls of the five-storey buildings decisively reduces the total earthquake bearing capacity of the building).

Table Nr. 6

Number of storeys	Natural vibration T [s]	ΔR [%]				
		I.	II.	III.	IV.	V.
1	$\leq 0{,}05$	10	19	29	38	48
2	$0{,}051 \leq T \leq 0{,}10$	9	19	28	37	47
3	$0{,}101 \leq T \leq 0{,}15$	11	20	30	39	53
4	$0{,}151 \leq T \leq 0{,}20$	11	22	32	42	53
5	$0{,}201 \leq T \leq 0{,}25$	12	25	38	50	62

5. AN EXAMPLE

We searched for the answer to the elemental question by measuring and processing on the building of Áprád Street 4. Nagyrév, Hungary: *What is the traffic caused masonry damage influenced by? Answer:* energy input.

The ratio of the traffic caused vertical acceleration/horizontal acceleration on this building is: a_V / a_H, the ratio of the vertical acceleration / soil acceleration is: a_V / a_T.

Table Nr. 7

Ratio of peak acceleration [m/s² / m/s²]					
X (a_V / a_H)		Y (a_V / a_H)		Ground (a_V / a_T)	
+	–	+	–	+	–
1,028	1,052	1,514	1,703	0,353	0,479
1,040		1,608		0,416	
1,324				0,416	
Ratio of measured acceleration at the peak frequencies [m/s² / m/s²]					
1,292		1,455		0,521	
1,373				0,521	
Average generated at Nagyrév					
1,3485				0,4685	

The repetition number is an estimated repetition number IM = 2,25.10^5

The tension ratio is the ratio $r = \sigma_{\min} / \sigma_{\max}$.

The result is a reduction in the bearing capacity

$$mc = 0{,}869$$
$$mt = 0{,}663$$
$$m\tau = 0{,}812$$

Measurability

Table Nr. 8

Change of proper period [s]		
Measured	Calculated	Changing
Tx = 0,0721	Tx = 0,0486	48,35 %
Ty = 0,0745	Ty = 0,0464	60,56 %

Using the 2 types of curves according to the standard MSZ EN 1998-1: S = 1,6; TB = 0,05 s; TC = 0,25s; TD = 1,2 s

Initial shear force

$$Sd(Tx) = 1{,}6 \cdot 0{,}12 \cdot 9{,}81 \cdot \left[\frac{2}{3} + \frac{0{,}0486}{0{,}05} \cdot \left(\frac{2{,}5}{1{,}5} - \frac{2}{3}\right)\right] =$$

$$= 3{,}08646144 \text{ m/s}^2$$

$$Sd(Ty) = 1{,}6 \cdot 0{,}12 \cdot 9{,}81 \cdot \left[\frac{2}{3} + \frac{0{,}0464}{0{,}05} \cdot \left(\frac{2{,}5}{1{,}5} - \frac{2}{3}\right)\right] =$$

$$= 3{,}00358656 \text{ m/s}^2$$

Cracked – on the basis if modified natural vibration

$$Sd(Tx) = 1{,}6 \cdot 0{,}12 \cdot 9{,}81 \cdot \frac{2{,}5}{1{,}5} = 3{,}1392 \text{ m/s}^2$$

$$Sd(Ty) = 1{,}6 \cdot 0{,}12 \cdot 9{,}81 \cdot \frac{2{,}5}{1{,}5} = 3{,}1392 \text{ m/s}^2$$

Increment

$$\Delta Sd(Tx) = 0{,}05273856 \text{ m/s}^2 \quad \rightarrow 1{,}708\%$$

$$\Delta Sd(Ty) = 0{,}13561344 \text{ m/s}^2 \quad \rightarrow 4{,}515\%$$

$$Q_S(Tx) = 83{,}846 \text{ kN}$$

$$Q'_S(Tx) = 85{,}279 \text{ kN}$$

Earthquake x basic shear force

$$Q_S(Ty) = 81{,}595 \text{ kN}$$

$$Q'_S(Ty) = 85{,}279 \text{ kN}$$

Earthquake y basic shear force

Reduction in bearing capacity

Table Nr. 9

Masonry	Initial	Modified	Reduction
	[N/mm²]		
Pressure	2,34	2,03346	13,09 %
Tension	– 0,14	– 0,09282	33,7 %
Shear	0,75	0,609	18,8 %
σ1	3,072	2,603	15,26 %
σ2	– 0,732	– 0,57	22,13 %
Safe	2,5	2,5	2,5
	Crack forming		
On pressed diagonal	1,229	1,0412	15,28 %
On drawn diagonal	– 0,293	-0,228	22,18 %

6. CONCLUSION

The researches should be expanded in order to know the traffic caused vibration better and for the used method.

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