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NUMERICAL ANALYSIS OF DYNAMIC FORCE ACTING PERPENDICULARLY ON A WALL MADE OF CONCRETE BLOCKS WITH RUBBER INSERTS

Abstract

In this paper numerical analysis considering the influence of dynamical force acting on wall made of concrete blocks with rubber inserts is presented. By examining the stress values on front and back surface of the analysed wall structure model, the effectiveness of proposed solution can be measured comparing to the wall made of concrete blocks without rubber inserts. Complete numerical analysis was performed in ADINA program.

Keywords

Mooney-Rivlin, FEM, Adina, nonlinear hyperelastic material, composite wall, damping.

1 INTRODUCTION

Nowadays various types of composite materials are widely used due to significantly better mechanical properties characterization of these materials. The most common materials used as composite structures in civil engineering are concrete and steel materials. By combining these two materials, structures with more efficient transfer of tensile and compressive stresses can be designed. Significant in design solutions are also composites based on the combination of steel and rubber, for example used as steel-rubber bearing assembles. These compounds allow to reduce vibrations which result from the moving vehicles, pedestrians etc. In nowadays technological and material solutions concerning utilization of composites only a small amount of research concern concrete-rubber materials.

Today a wide access to computers and software based on the finite element method allow to perform experimental tests of the model without the necessity of purchase expensive research equipment and materials. In addition, the use of such software allows the identification of various types of phenomena, such as the fluid flow influence on pipe elements stresses, the influence of temperature on structures, the effect of exposure to the electromagnetic field, as well as it becomes possible to analyse the propagation of mechanical waves.

As the precursors of rubber material research tests shall be deemed to Mooney and Rivlin, who have established mathematical model describing rubber materials behaviour [1, 2]. Zahorski continued these research and proposed modified mathematical model of rubber material behaviour under the influence of external loads [3, 4]. The study of reflection and evolution of the shock wave in selected hyperelastic materials were presented by Kosiński [5]. Moreover exactly the same author carried out experimental tests of wave propagation in layered composite material [6]. Modelling of wave phenomena in hyperelastic Mooney-Rivlin and Zahorski materials with the use of software based on the finite element method was presented in [7, 8]. There are also many publications describing the topic of finite element method use in civil engineering and mechanics, e.g. [9, 10].

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In this paper the numerical analysis concerning wall made of composite elements – concrete blocks with rubber inserts, which were connected via mortar is presented. Concrete blocks which transfer mainly compressive loads in a wall, during production technology process have embedded rubber inserts with properly adapted shape. According to that, wall properties allow to reduce the perpendicularly acting to the wall surface dynamic force impulse. The influence of impulse results in a mechanical wave propagation, which can be observed during the analysis of stress plots printed on the wall sections. The damping of mechanical wave propagation becomes then clearly visible in designed wall composite structure. The numerical analysis was performed to estimate the range of damping of transverse propagating mechanical wave in the wall made of concrete-rubber composites in relation to the wall made of solid concrete blocks. Percentage values of damping at the selected points on the reference frontal and rear surface of the composite wall structure in relation to the wall made of concrete blocks are presented. The influence of damping was also discussed in the paper [11]. In order to perform numerical analysis the ADINA program which is fully based on the finite element method was utilized. Rubber was defined as Mooney-Rivlin hyperelastic material model, concrete blocks were made of C20/25 concrete defined as ADINA Concrete material and mortars with strength of 4 MPa were defined as DF-Concrete, respectively.

2 HYPERELASTIC MOONEY-RIVLIN MATERIAL

The constitutive equations, also called as physical relationships describes the behaviour of the specified material medium under the influence of various type of external factors.

The constitutive relation for the hyperelastic Mooney-Rivlin material has the following form [1]:

$$W(I_1, I_2) = C_1(I_1-3) + C_2(I_2-3) \tag{1}$$

where: C_1, C_2 are the material constants, whereas I_1, I_2 are invariants of deformation tensor. According to the above showed condition, one can be stated that the elastic energy for the discussed incompressible, isotropic hyperelastic Mooney-Rivlin material is linearly dependent on deformation tensor invariants.

In Tab. 1 elastic constants for rubber considered in the work are presented. The values shown in the table are based on the study [3]. It should be noted that values of these constants were obtained via conversion to the SI system.

Tab. 1: Constants C_1, C_2

Constants	C_1 [Pa]	C_2 [Pa]
Rubber	$6.278 \cdot 10^4$	$8.829 \cdot 10^3$

In Tab. 2 strength parameters for analysed rubber (see [3]) are presented.

Tab. 2: Strength parameters for analysed rubber

Time of vulcanization in minutes at 143 °C	5
Strength in kN/m^2 at 500 mm/min	~$3.01 \cdot 10^4$
Strength in kN/m^2 at 5 mm/min	~$1.05 \cdot 10^4$
Elongation in % at 5 mm/min	~$5.81 \cdot 10^4$

3 THE NUMERICAL MODEL OF THE ANALYSED WALL

For the numerical analysis purposes, model of a wall with length equal 153 cm, height 129 cm and thickness 22 cm was adopted. Presented wall consists of concrete blocks, where each of them have the following dimensions: 50 cm length, 25 cm height and 22 cm thickness. Vertical and horizontal mortars in considered wall were assumed as 1 cm thick. Impulse load in the form of concentrated force with value of 1000 N was applied to the 6498 node, which was marked as point 1 in Fig. 1.

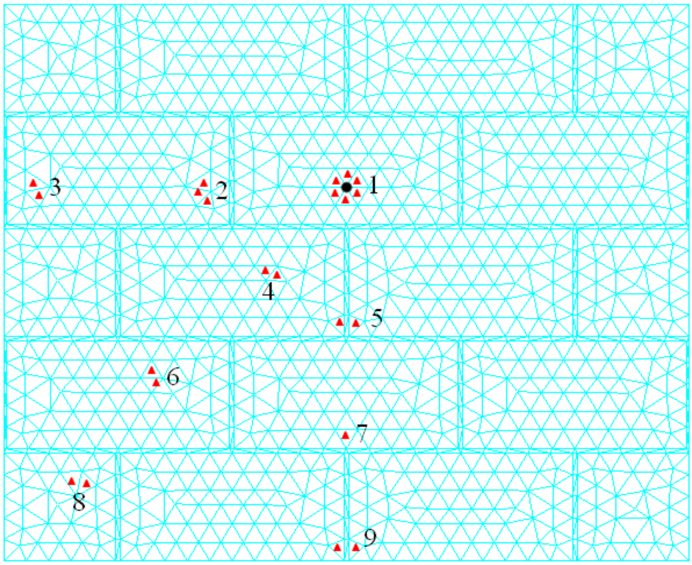

Fig. 1: Discrete model of the wall and effective stress measurement points 1-9. Points 1A to 9A are the reflection of points 1 to 9 located on the back side of the wall

Mentioned force reach its destined maximum value at $t = 1\times10^{-5}$ s and after that acting load is removed – its value is equal 0. Such determined force impulse result in disturbance propagation in the wall which is called as mechanical wave propagation. In the further time steps of performed analysis as a result of applied impulse force the effective stress values were read-out from the measurement points 1 – 9 (as shown in Fig. 1) and 1A – 9A, which are the reflection of points 1 to 9 located on the back side of the wall. For the effective stress values read-out two different time steps were adopted $t_1 = 1\times10^{-5}$ s and $t_2 = 6\times10^{-5}$ s, respectively. Red triangles in Fig. 1 denotes elements from which the average effective stress was read, whereas black dot shows place of applied concentrated force. The analysis was performed with the use of automatic time stepping module (ATS).

In the adopted model following boundary conditions were applied with respect to the Cartesian coordinate system presented in Fig. 2: bottom surface of the wall located on "XY" plane was fixed in the direction of "Z" axis, whereas side wall surfaces laying in the "YZ" plane were fixed both in the "X" and "Y" axis direction.

Discretization of considered wall model was performed with the use of 4-node 3D-solid finite elements (tetrahedrons), where size of each element was assumed to be ~0.05 m in the concrete blocks. Discretization of rubber and mortar areas was performed automatically with respect to the previously defined nodes on the concrete blocks. 11632 nodes and 50259 finite elements were obtained, where 32986 finite elements described the concrete blocks, 8455 finite elements described the mortar and 8818 finite elements described rubber volumes, respectively. In case of reference wall i.e. without the rubber inserts, 41804 finite elements were describing the concrete blocks, whereas 8455 elements were describing mortars. It was assumed that concrete blocks were made of C20/25 concrete, mortar connections had 4 MPa of compressive strength and rubber inserts were made of non-linear, hyperelastic Mooney-Rivlin material. On the basis of above mentioned assumptions following existing ADINA material models were assigned to the finite elements: concrete blocks – “Concrete”, mortars – “DF-Concrete”, rubber – “Mooney-Rivlin”, respectively.

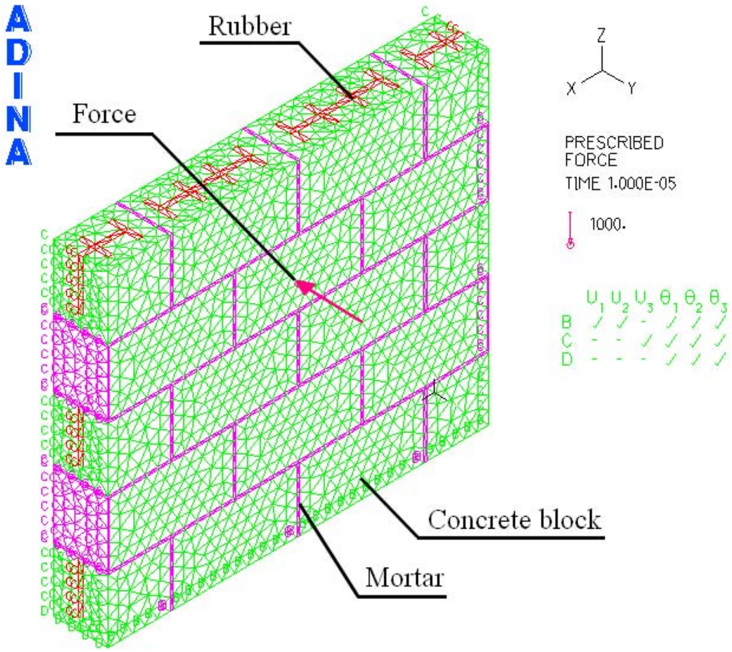

Fig. 2: Discrete model of the wall in ADINA program

4 NUMERICAL RESULTS

Comparison of the effective stress results obtained in the measurement points in the wall made of composites with relation to the wall made of concrete blocks without rubber inserts was presented in Tab. 3. It should be noted that points 1A to 9A are the reflection of points 1 to 9 and that points are located on the back side of the wall. Moreover in Figs. 3-5 effective stress redistribution in horizontal planar sections cutting through point 1/1A and 4/4A were presented.

According to the values presented in Tab. 3 and effective stress redistribution plots in Figs. 3-5 it was clearly visible that in the wall made of composites i.e. concrete blocks – rubber inserts the effective stress values corresponding to the propagation of mechanical wave were significantly reduced on the outer wall side (opposite side of applied impulse force) than in the wall made of solid concrete blocks (compare Fig. 4a, b). The increase of effective stress values near the point of applied impulse force in Fig. 4a was connected with the interference of reflected wave via rubber element. Moreover it should be noticed that in Fig. 5a and Fig. 5b, propagating wave refracts on the surface of rubber elements, whereas in the mortar wave was propagating similarly as in a solid concrete block.

In Fig. 6 and Fig. 7 percentage range of wave damping is presented between wall made of composite elements and wall made of solid concrete blocks for both: frontal surface of walls (measurement points 1-9) and back surface (measurement points 1A-9A) at time $t = 6 \times 10^{-5}$ s.

Comparing all obtained results it should be noted that despite the increase of effective stress in specified points of analysed structure, the composite wall which was made of the concrete blocks with rubber inserts allow to significantly reduce mechanical wave propagation up to 53% on the rest surface of this wall. This is a particularly important aspect in cases, where wall would be treated as a barrier from undesirable machine vibrations or other sources. In addition structure presented in this paper allow to transfer significant in-plane loads, which in other cases of composite structures with rubber elements is usually impossible due to large deformations.

Tab. 3: Comparison of effective stress obtained in selected measurement points for a wall made of composites and wall made of blocks without rubber inserts

Effective stress [Pa]					
		Wall (blocks with rubber)		Wall (simple blocks)	
Point	**Surf.**	**t = 0.00001 s**	**t=0.00006 s**	**t = 0.00001 s**	**t=0.00006 s**
1	**Front**	1.50E+05	3.19E+04	1.50E+05	2.58E+04
1A	**Back**	2.77E+00	9.86E+03	1.54E+01	1.13E+04
2	**Front**	6.45E-02	1.01E+03	6.33E-02	1.50E+03
2A	**Back**	1.14E-03	1.04E+02	1.43E-03	1.75E+02
3	**Front**	0.00E+00	2.08E-03	0.00E+00	2.85E-03
3A	**Back**	0.00E+00	3.43E-04	0.00E+00	4.66E-04
4	**Front**	7.22E-01	5.34E+03	6.72E-01	5.33E+03
4A	**Back**	2.46E-02	7.40E+02	2.52E-02	1.59E+03
5	**Front**	3.53E-02	1.95E+03	3.18E-02	1.95E+03
5A	**Back**	6.57E-03	3.51E+02	6.12E-03	2.70E+02
6	**Front**	0.00E+00	4.58E-02	0.00E+00	5.92E-02
6A	**Back**	0.00E+00	1.91E-02	0.00E+00	2.98E-02
7	**Front**	0.00E+00	3.88E-02	0.00E+00	5.33E-02
7A	**Back**	0.00E+00	2.79E-02	0.00E+00	3.92E-02
8	**Front**	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8A	**Back**	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	**Front**	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9A	**Back**	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Considering the chart from Fig. 6, only in point 1 there was a 24% increase of effective stress, which is connected with interference of reflected wave via rubber elements. In the points 2, 3, 6 and 7 the effective stress decreased in the range of 23 – 32%. In the points 8, 9 at the time step $t = 6\times10^{-5}$ s the effective stress was equal zero, which means that the propagation wave did not reached that measurement points at the specified time.

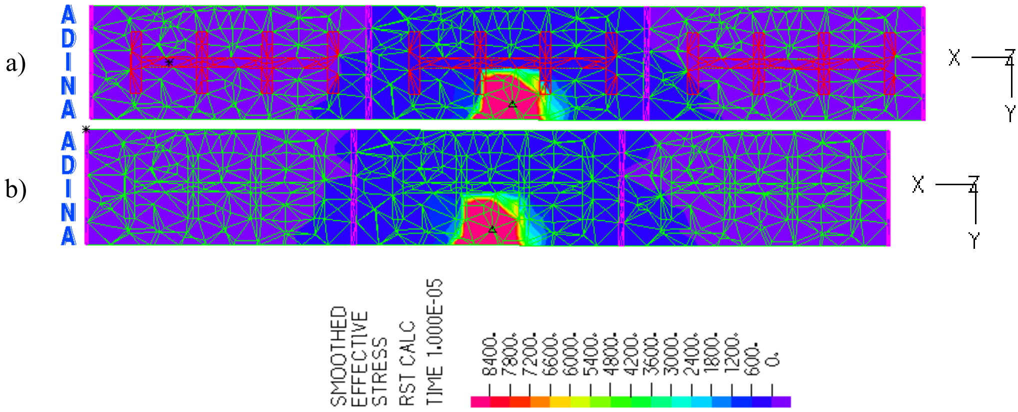

Fig. 3: Effective stress [Pa] at t = 0.00001 s in the horizontal plane section through point 1/1A, (a) composite wall made of concrete blocks and rubber material, (b) wall made of concrete blocks.

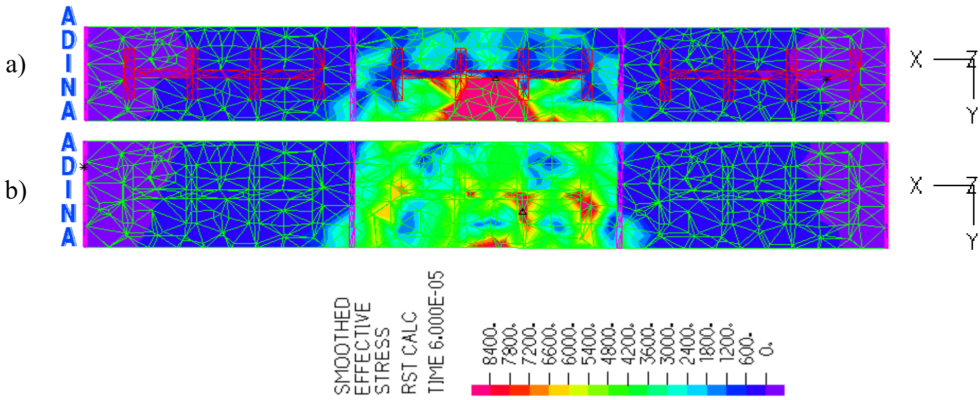

Fig. 4: Effective stress [Pa] at t = 0.00006 s in the horizontal plane section through point 1/1A, (a) composite wall made of concrete blocks and rubber material, (b) wall made of concrete blocks

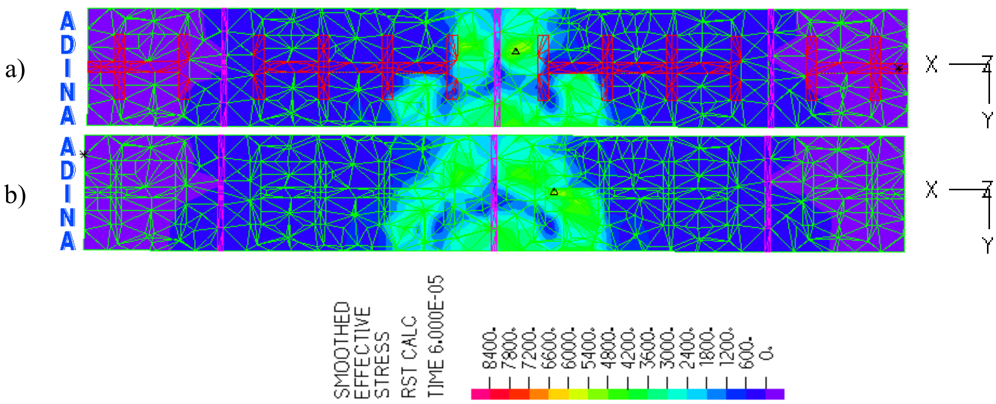

Fig. 5: Effective stress [Pa] at t = 0.00006 s in the horizontal plane section through point 4/4A, (a) composite wall made of concrete blocks and rubber material, (b) wall made of concrete blocks.

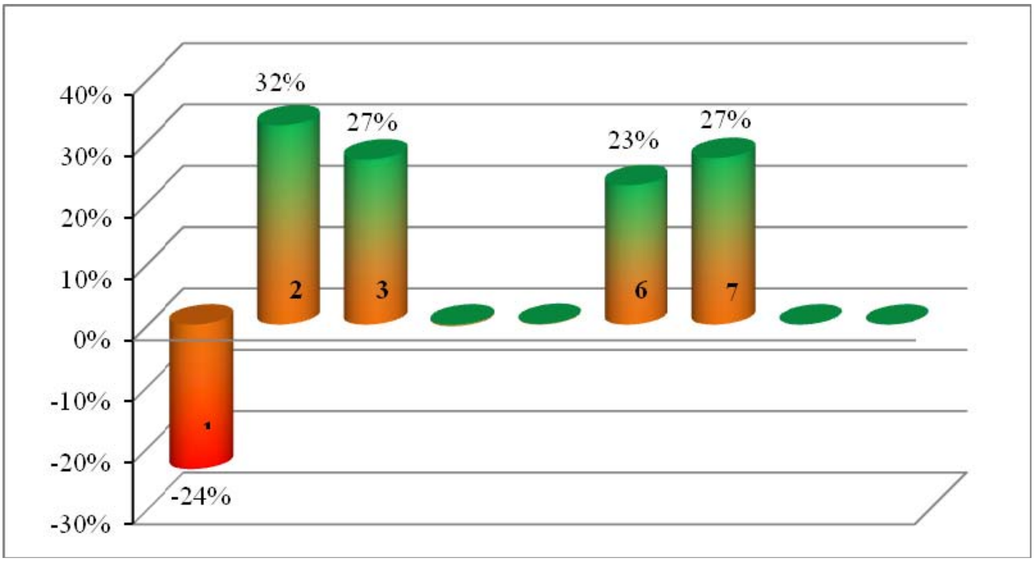

Fig. 6: Mechanical wave percentage damping on front „XZ" surface in the composite wall structure at t = 0.00006 s.

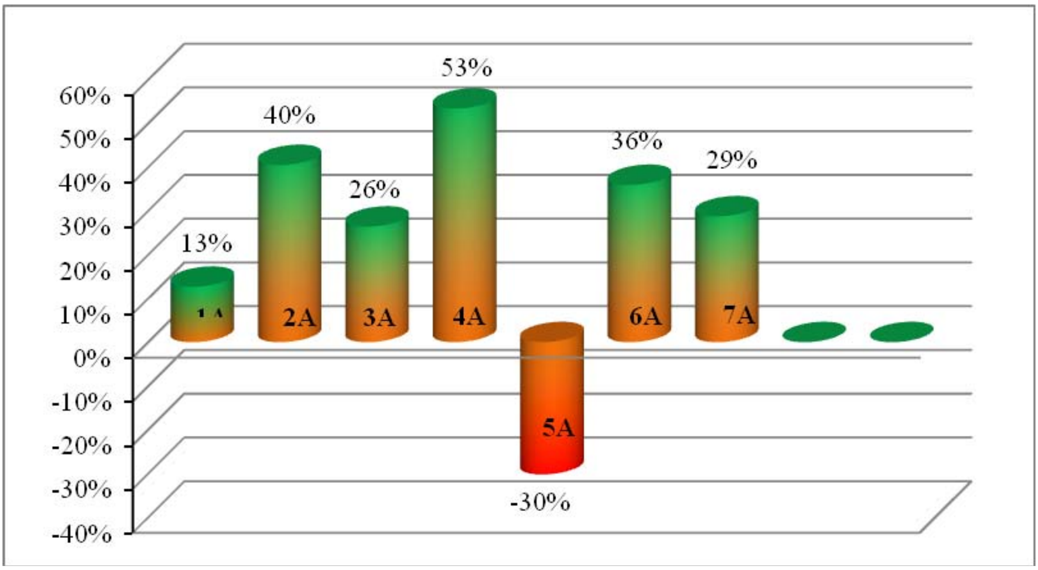

Fig. 7: Mechanical wave percentage damping on back „XZ" surface in the composite wall structure at t = 0.00006 s.

In the Fig. 7, where percentage mechanical wave damping on the back side of the wall was presented, it was observed, that depending on the measurement point location damping range varies from 13 – 53%. In the point 5A an increase in the effective stress was observed which was connected with fact, that the composite wall structure is inhomogeneous, there was a wave interference between two adjacent rubber elements. Moreover the mechanical wave was not suppressed by the rubber elements in the horizontal line from the point 1, where force was applied to the point 5A – wave propagates through concrete block and then through mortar (compare with Fig. 1).

5 CONCLUSIONS

Nowadays, as an acoustic insulation of building the most common material used are polystyrene and mineral wool, whereas composites made of a concrete blocks with the rubber pad could be treated as innovative material, which would allow both – transferring the compressive loads in construction and in addition could be used as a barrier from external sources of vibrations. The wall load bearing capacity would be slightly reduced as a result of applied in concrete blocks rubber inserts, while benefits would be much stronger. The connection of concrete and rubber material provides possibility to use these elements in places exposed to the mechanical vibrations. Moreover the implementation in production process of presented composite elements as a form of concrete blocks with rubber inserts could be simple from the technological point of view. Special metal form could be embedded in concrete blocks at the beginning of production, further that form would be removed and then the rubber pad would be inserted or rubber material could be injected.

Production, exploitation and then disassembly of construction made of presented composites would not affect negatively on the natural environment. Both rubber and concrete are materials which can be recycled. It is also worth to notice that currently performed numerical analyses allow to reduce costs of designing the innovative materials than with the use of traditional laboratory experimental test. The presented in this paper idea of composite wall is only a concept model, which can be treated as introduction for further modify and experimental tests this type of structures.

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