Numerical Modelling for Energy Absorption of Reinforced Concrete Barriers Covered with Natural Rubber

Lwin Lwin Aung1, Amphon Jarasjarungkiat2, Suvisit Banyam

[1,2]*Department of Civil Engineering, Faculty of Engineering, King Mongkut's institute of Technology Ladkrabang, Bangkok, Thailand.*

[1]*Corresponding author; E-mail address: lwinlwinaung2281995@gmail.com*

Abstract.

Due to the oversupplying, applications of natural rubber are widely introduced in Thailand. In this research, a deployment of natural rubber with typical road safety concrete barrier is investigated numerically. There are many various kinds of barriers to be used not only to prevent vehicles from collision with an opposite vehicle but also to protect from roadside hazards. Therefore, nonlinear finite element modelling was employed to investigate the more efficiencies of barrier covered with rubber sheets by means of finite element analysis. The three-dimensional model is involved with three different homogeneous materials under static analysis while applying an area load representing a car colliding to the barrier. The results have shown that barrier with rubbers can absorb impact force from the vehicles.

Keywords. -

1. INTRODUCTION

Nowadays, amount of producing rubber is increased in Thailand and also many concrete barriers are applied for safety on the road to reduce the danger of accidents. To attain safe roadways, there are three facts by [9] such as safer people —to limit the driver not to drive after drinking alcohol, to use seatbelts while driving, safer vehicles —to apply optimum safety devices for vehicles and safer roads — to build and maintain roads, to improve safety barriers. Many researchers mainly focus on the strength of concrete, however, in this paper, the authors focus on using rubber latex not only to improve the strength of barriers but also not to damage cars. Analysis of barrier by means of experimental test is expensive, therefore, simulation with theoretical finite element with various software is quite easy to apply to test the model. Among them, LS-DYNA, ANSYS, ABAQUS and Virtual CRASH 4.0 (2019) were used to analyze the strength of concrete barriers by [8],

[6], [3], [1] and [2]. In this paper, numerical simulation is carried out concrete damage plasticity (CDP) barrier with or without rubber to compare how much energy they stored

2. Finite Element Modelling of Barrier

The non-linear finite element under Standard was employed to CDP concrete reinforced barrier covering with or without rubber.

2.1. Modelling of concrete barrier

In the finite element software, the following equations are used to find the uniaxial compressive and tensile behavior to create concrete damage plasticity model to examine the sensitivity of the damage while predicting formation of cracks in concrete [5].

Uniaxial Compressive Behavior

$$\sigma_c=(1-d_c)E_0(\varepsilon_c-\varepsilon_c^{pl}) \tag{2.1}$$

$$\varepsilon_c^{in}=\varepsilon_c-\sigma_c/E_0 \tag{2.2}$$

$$\varepsilon_c^{pl}=\varepsilon_c^{in}-d_c/(1-d_c).\sigma_c/E_0 \tag{2.3}$$

Uniaxial Tensile Behavior

$$\sigma_t=(1-d_t)E_0(\varepsilon_t-\varepsilon_t^{pl}) \tag{2.4}$$

$$\varepsilon_t^{ck}=\varepsilon_t-\sigma_t/E_0 \tag{2.5}$$

$$\varepsilon_t^{pl}=\varepsilon_t^{ck}-d_t/(1-d_t).\sigma_t/E_0 \tag{2.6}$$

where σ_c and ε_c were nominal compressive stress and strain, d_c and d_t were two scalar damage variables, E_0 was the initial (undamaged) elastic stiffness of the material, $\varepsilon^{pl}{}_c$ and $\varepsilon^{pl}{}_t$ were plastic hardening strain in compression and tension, $\varepsilon^{in}{}_c$ was inelastic hardening strain, σ_t and ε_t were nominal tensile stress and strain and $\varepsilon^{ck}{}_t$ was hardening cracking strain respectively. Although the uniaxial compressive and tensile behaviour could be explored by experimental tests, in this study, simplified concrete damage plasticity with 20 grades by [4] was used and data was shown in Table 1. The concrete barrier with 2.4E-009 kg/mm3 was 600 mm wide at the base, 300 mm wide at the top and 1 m high. The 25 mm diameters reinforced steels and 9 mm stirrups at 75 mm apart from each other were embedded in the concrete as shown in Figure 1(a). Moreover, the density of steel 7.8E-009 kg/mm^3, the elastic modulus 21000 MPa and 0.3 poison ratio was applied.

2.2. Properties of rubber sheet

There are different forms for strain energy potential to evaluate hyper-elastic material behavior such a s Arruda-Boyce, Marlow, Mooney-Rivlin, Neo-Hookean, Ogden, Polynomial, Reduced polynomial, Van der Waals and Yeoh form. Among them, Mooney-Rivlin, Neo-Hookean and Ogden are famous for materials like rubber. However, in this paper, Mooney-Rivlin form was employed.

Table 1 Material Properties for Concrete with SCDP Model in Class B20

Material's Parameters	B20	Plasticity Parameters	
Concrete Elasticity		Eccentricity	0.1
E (GPa)	21.2	Fb0/fc0	1.16
	0.2	K	0.67
Concrete Compressive Behaviour		Concrete Compression Damage	
10.2	0	0	0
12.8	7.73585E-005	0	7.73585E-005
15	0.000173585	0	0.000173585
16.8	0.000288679	0	0.000288679
18.2	0.000422642	0	0.000422642
19.2	0.000575472	0	0.000575472
19.8	0.00074717	0	0.00074717
20	0.000937736	0	0.000937736
19.8	0.00114717	0.01	0.00114717
19.2	0.001375472	0.04	0.001375472
18.2	0.001622642	0.09	0.001622642
16.8	0.001888679	0.16	0.001888679
15	0.002173585	0.25	0.002173585
12.8	0.002477358	0.36	0.002477358
10.2	0.0028	0.49	0.0028
7.2	0.003141509	0.64	0.003141509
3.8	0.003501887	0.81	0.003501887
Concrete Tensile Behaviour		Concrete Tension Damage	
Yield Stress (MPa)	Cracking Strain	Damage Parameter T	Cracking Strain
2	0	0	0
0.02	0.000943396	0.99	0.000943396

The form of the Mooney-Rivlin strain energy potential

$$U = C_{10}(\overline{I}_1 - 3) + C_{01}(\overline{I}_2 - 3) + 1/D_1.(J^{el} - 1)^2 \tag{2.7}$$

$$\overline{I_1} = J^{(-1/3)}(\lambda_1^2 + \lambda_2^2 + \lambda_3^2) \text{ and } \overline{I_2} = J^{(-1/3)}(\lambda_1^{(-2)} + \lambda_2^{(-2)} + \lambda_3^{(-2)}) \tag{2.8}$$

Hence, U was strain energy per unit of reference volume, C_{10}, C_{01} and D_1 were temperature-dependent material parameters, $\bar{I}_1$ and $\bar{I}_2$ were the first and second deviatoric strain invariants, J^{el} was the elastic volume ratio, J was total volume ratio and λ was the principal stretches. However, C_{10} and C_{01} were applied as 0.142 and 0.011 from the material parameters of [7].

The 1500 mm × 500 mm × 15 mm rubber sheets were attached to concrete barrier. The rubber latex was separated three parts to cover the front, back and top of concrete barrier instead of using only one sheet of rubber to avoid maximum distortional errors. In finite element analysis, tie function was applied to attach rubber sheets as slave with concrete as master surfaces. For contact property, frictionless and hard contact were submitted as Figure 1(b).

3. Investigation of Barrier Strength Based on using Finite Element Analysis

In this section, the non-linear finite element under static analysis was carried out. Moreover, the light passenger car, 2,300lbs (1,043kg) with NCHRP – TL3 (100 kph) by [2] speed within crushing time 2 seconds was assumed to analyze by using Newton's second law of motion:

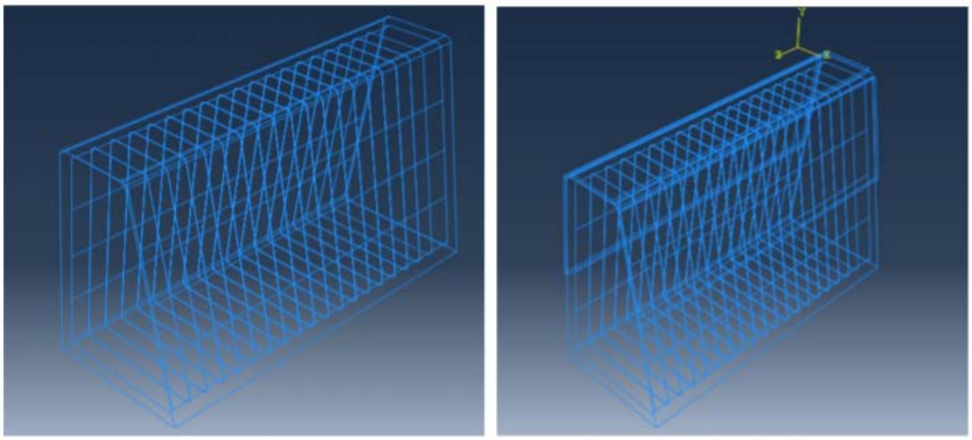
$$\text{Force} = \text{mass} \times (\text{velocity}/\text{time}) \tag{3.1}$$

Therefore, the total load (14,500 N) was applied to the 375mm x 250mm area on the front surface of barrier with or without rubber sheets. The simulation was carried out to investigate the capabilities and strength of reinforced barrier containing with various elastic modulus and properties between concrete and natural rubber

Then, finite element mesh was provided to each model. There are many different control mesh assignments and also mesh element shapes like hexahedral, hexahedral-dominated, tetrahedral and wedge. The mesh element shape is based on element type to assign the mesh while choosing element family and geometric order and shape of specific element controls. In this field, hexahedral element shape with sweep technique and reduced integration was used for concrete and structure technique with hybrid formulation was selected for rubber. The linear 3D stress was defined for barrier and rubber; however, the linear truss was selected for steels as Figure 2.

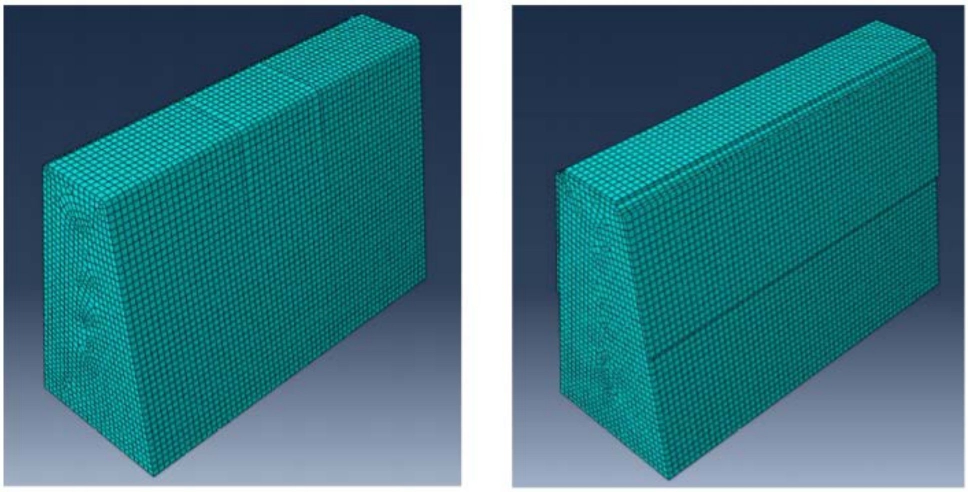
4. Results and Conclusion

The results were shown that the barrier covering with rubber latex could absorb impact force from crushing test than the one without covering with rubber. Moreover, the principal stress without attaching is higher than with rubber as Figure 3. The graph from Figure 3 was shown that the values of positive maximum principal stress in the concrete and negative maximum principal stress in the rubber. The costs of concrete barrier covering with natural rubber is around 102USD/ Meter by [2]. The cost is less than the cost of accident cost. Moreover, using natural rubber can reduce the damage of vehicles and injuries for road users. Then, the consuming rates for rubber can be increased and the people who produce rubber can get profits than the previous days.



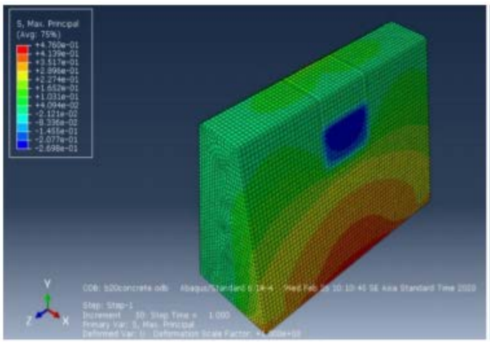
(a) Concrete barrier without rubber (b) Concrete barrier with rubber

Figure 1 Barrier Models with Finite-Element

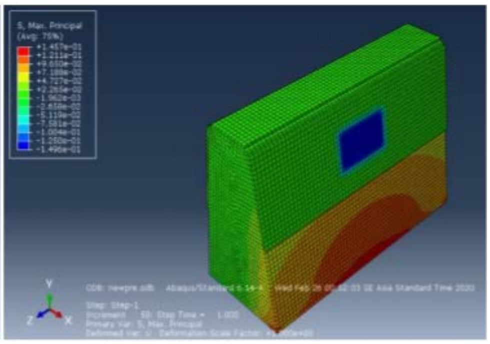


(a) Concrete barrier without rubber (b) Concrete barrier with rubber

Figure 2 Barrier models with finite-element meshing



(a) Concrete barrier without rubber



(b) Concrete barrier with rubber

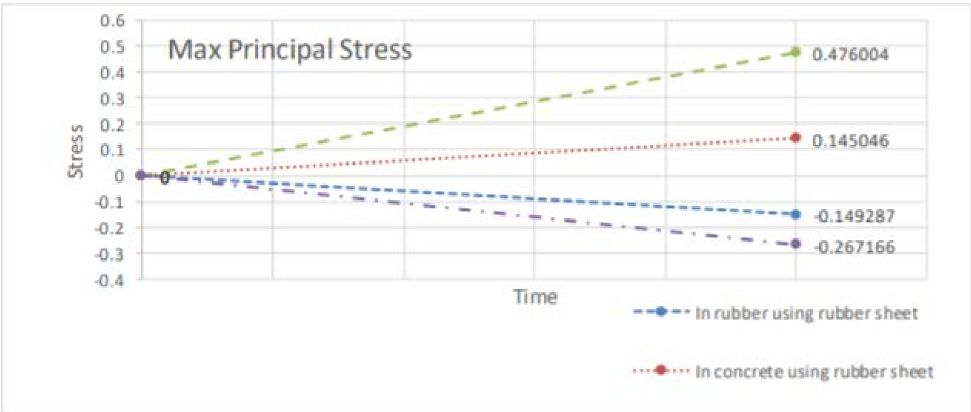


Figure 3 Maximum principal stress of concrete barrier

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