CHEMICAL ENGINEERING TRANSACTIONS

VOL. 46, 2015

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Peiyu Ren, Yancang Li, Huiping Song

ISBN 978-88-95608-37-2; **ISSN** 2283-9216

DOI: 10.3303/CET1546111

Experimental Study on Application of Used Tires in Rock Shed Cushion Layer

JianHu Sun, ZhaoJun Chu, Weiming Luo, Min Wang*

Department of Civil Engineering, Chongqing Key Laboratory of Geomechanics & Geoenvironmental Protection in Department of Civil Engineering, Logistical Engineering University, Chongqing, China, 401311.
Wangmin198217@163.com

The used tires cushion layer for rock sheds can take advantage of tires radial stiffness and deformation ability, cushioning rockfall impact to protect the rock sheds roof. Quasi-static compression and pseudo-static test results show that: Bare used tires with small radial stiffness and good radial elasticity cannot dissipate rockfall impact energy. Bare used tires can be used as cushioning material. Winded with steel wire and filling sand bag can increase the tires radial stiffness and improve its bearing capacity. The effect of filling sand bag is better than winding wire under the same condition, and will also be more economical. Winding wire and filled with sand bag can make used tire perform significant non-linearity character under radial stress, so it has an improved energy dissipation capacity. Tires can absorb energy after winded with wire and filled with sand bag and tires filled with sand bag will perform better in absorbing impact energy than that of winded with wire. Better energy absorption characteristics of tires filled with soaking sand bag is found in pseudo-static test.

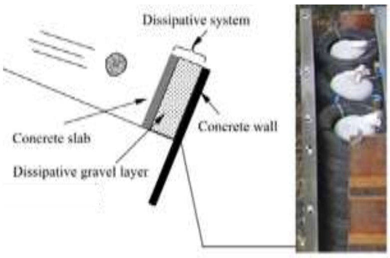
1. Introduction

In mountainous region, frequent occurrence of geological disasters poses a serious threat to buildings and public infrastructures. Roads and railways that passing through mountains or valleys are usually exposed to rockfall hazards and thus people will suffer from traffic suspend, vehicle damage and personal injury. Recent years, scholars worldwide carried out extensive studies on rockfall hazards, proposing many rockfall hazard protection measures to reduce accidents and losses caused by rockfall disasters. Rockfall protection measures can be divided into active protection measures and passive protection measures. The passive protection measures contain many structure types such as stone-blocking fences, flexible protection system, rock shed, retaining wall and dam (Huang et al (2010), Wang (2011), Volkwein (2011)). They vary in structural form, protection energy capacity, thus can be used in different engineering situation (Descoeudres1997)). Rock shed, with high protection energy capacity, can provide direct and effective protection without changing traffic routes. Thus rock shed is widely adopted in traffic engineering as rockfall protection measures (Wang et al (2014)).

In order to mitigate the rockfall impact on rock shed, energy dissipation components or cushion layer are necessary. Delhomme et al (2005) and Mommessin et al (2004) proposed setting short concrete filled steel tube members between pillar and cover plate in rock shed, and studied the deformation and energy absorption characteristics of the supporting member through test and theoretical analysis. However, the supporting member needs to be replaced when it reaches a certain deformation, which is unfavorable in engineering applications. Cushion layer on top of cover plate is a better approach, the cushion layer can disperse contact stress between rockfall and cover plate, reduce rockfall motion acceleration, extend function time that rockfall impact on cover plate, thus reduce the peak impact force of rockfall on plate (Volkwein (2011)). Due to economic reasons, gravel and soil is often used as cushion layer material in engineering (Ishikawa (1999)). Study on gravel as cushion layer material in rock shed is carried out extensively. Yoshida et al (2007) and Tam et al (2013) conducted test and theoretical analysis on the sand cushion layer. Schellenberg et al (2006,2008,2008) and Gerber et al (2008) proposed a new type cushion system composed of wire mesh, foam glass and carried out large tests outdoors and theoretical analysis, results manifest cushion layer with a excellent energy dissipating effect. Lorentz et al (2008) proposed a sandwich structure composed of

Please cite this article as: Sun J.H., Chu Z.J., Luo W.M., Wang M., 2015, Experimental study on application of used tires in rock shed cushion layer, Chemical Engineering Transactions, 46, 661-666 DOI:10.3303/CET1546111

reinforced concrete slab, gravel and tires (Fig. 1) and studied its performance through test. Wang et al (2014) put forward cushion layer composed of polyurethane foam and conducted experiments and numerical simulations.



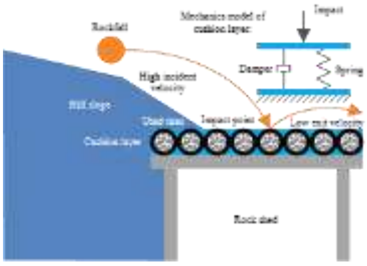


Figure 1: Sandwich structure proposed by Lorentz et al (2008) *Figure 2: Schematic of used tire cushion layer*

A cushion layer with combination of used tires, wire and sand bags (Fig. 2) is proposed here and the cushion layer can be simplified as spring-damper model, with elastic deformation capacity and energy dissipation capacity. Quasi-static and pseudo-static tests carried out on a single used tire demonstrate its mechanical properties under different conditions which provide a reference for testing and numerical simulation of the new cushion layer. And then optimization design and application of the new cushion layer can be carried out.

2. Quasi-Static tests on used tire

2.1 Used tire cushion layer

Used tire cushion layer is composed of used tires, wires and sand bags. Used tires as elastic material can recover after rock impact with little remaining deformation, so the used tires can be reused during the service time of rock shed without maintenance. Wires and sand bags adopted as energy absorbing materials which can assimilate impact energy during rock impact. So the new cushion layer will reduce peak impact force and assimilate rock impact energy while rockfall strike on the rock shed slab.

Used tire cushion layer using in rock shed should have appropriate rigidity and elasticity. The cushion layer should deform within a certain extent during the impact with little or no deformation left after rockfall impact, or else the cushion layer may need frequent repair and thus increase the engineering cost. During the cushion layer deformation under rockfall impact, wires and sand bags deform at the meanwhile and can absorb energy through deformation and sand friction.

2.2 Materials and methods

Test material include model 165/70R13 used tires, bags filled with ordinary river sand with opening fastened and 3.4mm galvanized wire. The used tire tread pattern has been worn flat without hurt the belt and without any mechanical damage, cracks or holes. Test uses MaxTest program controlled universal testing machine and loading speed is set to displacement control with velocity of 50mm/min. As in engineering application, cushion layer will work normally with small deformation during rock impact, so in the compress test, tire deformation limit is 100mm. While placing tire on MaxTest machine, LAiSAi laser sighting device is used to ensure the tire is vertical.

Quasi-static test is carried out with three conditions (Fig. 3). The first set is “bare tires” which is only used tires without sand bag or steel wire. The second set is “tires + wire” which is tires winded with wire along the circumference. The last set is "tires + wire + sand bag" which is tires filled with sand bag and winded with wire along the circumference. Single tire weight under different conditions is shown in Table 1.

Table 1: Average tire mass under different condition

Condition	Bare tire	Tire + wire	Tire + wire +sand bag
Mass/kg	5.95	12.7	30.6

2.3 Test results and analysis

Test results shown in Fig. 3 show that: winded with steel wire and filling with sand bag can both increase bearing capacity and improve rigidity. The average rigidity of the first set is about 8646N/m, the second set is about 16399N/m and the third set is about 51619N/m, which means, with same deformation, used tire winded with wires or filling with sand bags can withstand larger force. Take the 60mm radial deformation as an example, the bearing capacity of the first set is 0.55kN. The bearing capacity of the second group is

1.30kN with 136.36% increase comparing with the first set. The bearing capacity of the third group is 3.50kN with 536.36% increase comparing with the first set. Besides the bearing capacity increase, the force-deformation curves show some nonlinearity after used tires winded with wires and filled with sand bags which will contribute to energy dissipation capacity.

In engineering applications, used tires weight should be taken into consideration, bearing capacity increase provided by wires and sand bags per mass unit is concerned. Take the 60mm radial deformations as an example, bearing capacity per mass unit are as follow: the first set is 92.44N/kg. The second set is 102.36N/kg with 10.74% increase comparing with the first set. The third set is 114.38N/kg with 23.74% increase comparing with the first set.

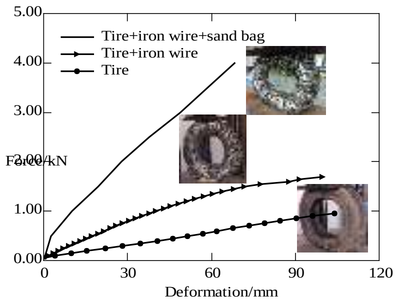


Figure 3: Static compression tests of tires

So it is obvious that winding wire and filling sand bag can increase the bearing capacity of the tires and filling sand bag is better than winding wire. Taking cost factor into account, filling with sand bag is more desirable. Wire is more expensive than sand filled bag and winding wire is more laborious than sand bag filling. That is to say, filling sand bag is more economic than winding wire. Besides, bearing capacity per mass unit of tires filling with sand bag is higher than that of tires winded with wire.

3. Used tires pseudo-static experimental study

3.1 Materials and methods

Pseudo-static test use PLU-1000kN hydraulic servo multi-channel pseudo-static test systems with loading range of ± 100mm(shown in Fig. 4), variable amplitude loading is adopted and loading speed is set to 300mm/min. The initial displacement is ± 0mm, loading cycle will repeated 10 times from ± 10mm to ± 100mm for each set of specimen, in each loading cycle, tire will be compressed first and then stretched, so the displacement is positive first and then negative. The first loading cycle displacement limit is ± 10mm, then each cycle displacement limitation will increase 10 mm. The 10th cycle loading amplitude is ± 100mm. And at last displacement will go back to zero. Then the tire can be replaced with new specimen.

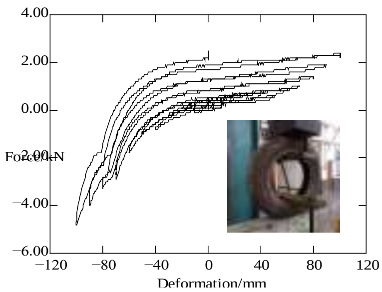
Figure 4: Pseudo-static test of tires

Test material is the same as mentioned above in quasi-static compress test, but the test condition change to 4 sets (Fig. 5): The first three sets are all the same as the quasi-static test. The fourth set is "tire + wire + saturated sand bag", i.e., the sand bag is first soaked with water and then filled into the tire, the tire with filling saturated sand bag will be winded with wire at last.

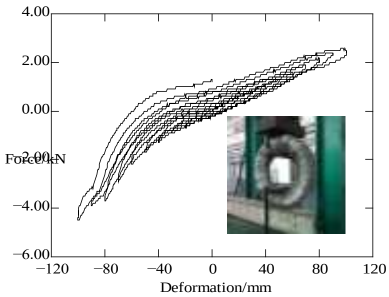
3.2 Test results and analysis

The test results under 4 different conditions are shown in Fig. 5. In test set 1, the tire performs good linear elasticity in compress stage and show nonlinearity in stretch stage. Closed curve does not appear in any loading cycle, which indicates that the tire deformation is majorly elastic deformation and no energy is absorbed within any loading cycle.

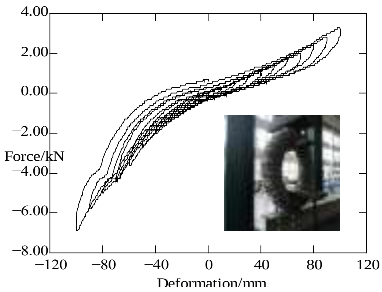
In contrast, closed force-deformation curves emerge in 2-4 sets test, which indicate that some energy is absorbed in loading cycle. Compared with set 2, tire energy dissipation capacity is enhanced in set 3 with filling sand bags. And set 4 with sand bag soaking, energy dissipation capacity witness a great increase. Taking ± 100mm hysteresis curves for example, ± 100mm closed curve of set 3 enclose an area of energy 219.60N·mm. ± 100mm closed curve of set 4 enclose an area of energy 378 .25N·mm, with 72.25% increase compared with set 3. Table 2 shows the tire energy dissipation capacity in ± 100mm loading cycle.



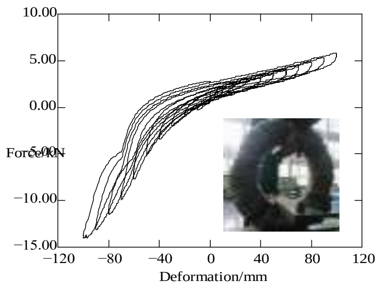
(a) Bare tires



(b) Tires + wire



(c) Tires + wire +sand bag



(d) Tires + wire + saturated sand bag

Figure 5: Results of tires pseudo-static test

Table 2: Tire energy dissipation capacity under different condition

Loading amplitude/mm	Energy dissipation/ N·mm		
	Set 2	Set 3	Set 4
±10	2.94	3.21	9.78
±20	7.83	9.88	23.22
±30	15.53	21.34	56.92
±40	23.72	34.49	85.81
±50	34.05	45.55	120.97
±60	54.85	65.98	198.43
±70	61.66	97.71	245.03
±80	77.87	115.28	289.57
±90	94.22	155.71	331.69
±100	122.00	219.60	378.25

In engineering applications, cushion layer basically working under rock impact, the energy dissipation mainly depends on tire compress deformation and its recovery stage, curve surrounded area in the first quadrant hysteresis shown in Fig. 6 has practical significance. Tests showed: winded with wire and filled with sand bag can both improve energy dissipation capacity, and filled with sand bag is better, especially filled with saturated sand bag. Energy absorbed during deformation of tires winded with wire mainly depends on deformation of wire. Plastic accumulated fatigue during wire deformation will cause problem in durability, so tires winded with wire as energy absorber may need to be replaced during service time, which is not conducive to engineering applications.

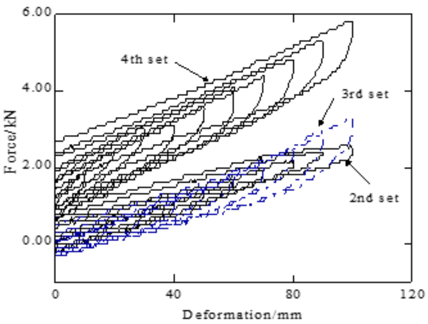


Figure 6: Tire energy dissipation capacity comparison of 2nd, 3rd and 4th set

Energy absorbed during deformation of tires filled with sand bag mainly depends on friction between sand particles, friction between sand bags and friction between sand bag and inner tire wall. Saturated sand bag can increase the degree of compaction of sand bag and filling compaction of sand bag in tires, increase friction between the sand bags, thus improve tire energy dissipation capacity. Although tires filled with saturated sand bag is not impractical for engineering applications, but it is meaningful for finding means of improving tire energy dissipation capacity. In order to improve tire energy dissipation capacity, we can choose sand with good material property and adopt engineering measures to improve the filling compaction degree, increasing friction between sand, sand bags, sand bags and tire.

4. Conclusions

Used tires is proposed to using in rock shed cushion layer, effect of winding wire and filling sand bag on improving tires stiffness and energy dissipation capacity is studied through quasi-static tests and pseudo-static tests, the results show that:

(1) Winding wire and filling sand bag can increase the stiffness and bearing capacity of used tires. Bare tire radial stiffness is 8646 N/m, tire stiffness after winding wire increase to 16399 N/m, and tire stiffness after filling sand bag and winding wire is 51619 N/m. With the same weight, tires filling with sand bag perform better than tires winded with wire. With the same tire radial deformation of 60 mm, the bare tire carrying capacity is 92.44N/kg, tire winded with wire is 102.36N/kg, tires filled with sand bag and winded with wire is 114.38N/kg.

(2) Displacement-force curve of tires winded with wire or filled with sand bag under radial loading show significant nonlinearity, which will improve tire energy dissipation capacity. Bare tire under radial loading shows good linear elastic, with no energy absorption. Bare used tires can be used as cushioning material. Tires winded with wire or filled with sand bag can dissipate rock fall energy. Tire filled with sand bag performs better per mass unit and with better economic performance.

(3) Tires filled with saturated sand bag and winded with wire perform good energy absorption characteristics in pseudo-static tests which is meaningful for finding measures to improve the tires energy dissipation capacity. Research has reference sense for further study of used tires cushion layer.

Acknowledgment

This work was supported by grant from National Natural Science Foundation of China (NO. 51378495, NO. 51408602), Chongqing Natural Science Foundation (cstc2012jjA30005, cstc2012jjB30004) and Bureau of Land Resources and Housing Management of Chongqing.

Reference

Delhomme F., Mommessin M., Mougin J. P., et al, 2005, Behavior of a structurally dissipating rock-shed, experimental analysis and study of punching effects, International Journal of Solids and Structures, 42(14), 4204-4219, DOI:10.1016/j.ijsolstr.2004.12.008

Descoeudres F., 1997, Aspects géomécaniques des instabilités de falaises rocheuses et des chutes de blocs, Publication de la Société Suisse de Mécanique des Sols et des Roches, 135, 3-11.

Gerber W., Volkwein A., Denk M., 2008, Impact of rockfalls on reinforced foam glass cushion systems, Volkwein A, Labiouse V, Schellenberg K. Proceedings of Interdisciplinary Workshop on Rockfall Protection, Morschach, June 23-25, 31-33.

Ho T.S., Masuya H., Takashita N., 2013, Experimental study concerning impact characteristics by collision of weight on sand cushion over steel beam, International Journal of GEOMATE, 4(1), 471-476.

Ishikawa N., 1999, Recent progress on rock-shed studies in Japan, Masuya P, Labiouse V. Joint Japan-Swiss Scientific Seminar on Impact Load by Rock Falls and Design of Protection Structures, Kanazawa, Ishikawa, October 4-7, 1-6.

Lorentz J., Perrotin P., Donzé F., 2008, A new sandwich design structure for protection against rockfalls, Volkwein A, Labiouse V, Schellenberg K. Proceedings of Interdisciplinary Workshop on Rockfall Protection, Morschach, June 23-25, 58-60.

Mommessin M., Agbossou A., Delhomme F., et al, 2004, Horizontal and slanting reinforced concrete slabs for structurally dissipating rock-shed, experimental analysis, Li V C, Leung C K Y, Willam K J, et al. Fracture Mechanics of Concrete Structures, Volume 2, Proceedings of the Fifth International Conference on Fracture Mechanics of Concrete and Concrete Structures, Vail, Colorado, April 12-16, Farmington Hills, American Concrete Institute, 965-972.

Schellenberg K., Volkwein A., Denk M., et al, 2008, Falling weight tests on rock fall galleries with cushion layers, Volkwein A, Labiouse V, Schellenberg K. Proceedings of Interdisciplinary Workshop on Rockfall Protection, Morschach, June 23-25, 99-101.

Schellenberg K., Volkwein A., Roth A., et al, 2006, Rockfall - Falling weight tests on galleries with special cushion layers, Majorana C, Salomoni V, Lok T S. Proceedings of the 3rd International Conference on Protection of Structures Against Hazards, Venice, Italy, September 28-29, 251-258.

Schellenberg K., 2008, On the design of rockfall protection galleries, ETH Zürich, DOI: 10.3929/ethz-a-005711071

Volkwein A., Schellenberg K., Labiouse V., et al, 2011, Rockfall characterisation and structural protection - a review, Natural Hazards and Earth System Sciences, 2011(11), 2617-2651, DOI: 10.5194/nhess-11-2617-2011.

Wang D.P., He S.M., Wu Y., et al, 2014, Cusioning effect rock sheds with EPS cusion on rock-falls action, Journal of Vibration and Shock, 33(4), 31-35, DOI:10.3969/j.issn.1000-3835.2014.04.036

Wang M., Shi S.Q., Kang J.G., 2011,Numerical and theoretical analysis of dissipation energy capacity of ring net impacted by rockfall, Journal of Vibration and Shock, 30(3), 10-13, 21, DOI:10.3969/j.issn.1000-3835.2011.03.003

Yoshida H., Nomura T., Wyllie D.C., et al, 2007, Rock fall sheds - application of Japanese designs in North America, Schaefer V R, Schuster R L, Turner A K. Landslides/slope instability AEG Special Publication, Conference presentations from the 1st North American Landslide conference June 3-8, Vail, Colorado. Denver, The Association of Environmental & Engineering Geologists, 179-196.

Yu H., Sun Q.D., Xu Q., 2010, New development of rockfall kinematics study, Journal of Vibration and Shock, 29(10), 199-203, 214, DOI:10.3969/j.issn.1000-3835.2010.10.007