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COLLISION BEHAVIOURS OF RUBBERIZED CONCRETE

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ABSTRACT

Rubberized concrete is recommended for highway barriers. It was observed that rubberized concrete's acquired competency to absorb energy resulted in a decrease in damages and injuries during the collision of vehicles with barriers. In this study, normal concrete was combined with two different sizes of rubber aggregate in order to examine the behaviours of rubberized concretes under collision impact. This was done through the comparison of experimental results. The collision impacts were researched as a dynamic problem, and the static results pertaining to cylindrical samples were converted into dynamic values. The values obtained were compared with values for both normal concrete and steel. The results showed that the impact resistance of rubberized concrete was higher, and it was particularly evident in concrete samples aggregated with thick rubber. © *1997 Elsevier Science Ltd*

Introduction

The purpose of aggregating rubber is to increase concrete's flexibility, elasticity, and capacity to absorb energy. According to the results of the experiments, it was determined that the addition of rubber aggregate into concrete does in fact increase concrete's impact resistance. This resistance is derived from rubberized concrete's increased ability to absorb energy, safety, and insulate sound during impact (1–8). Furthermore, the increase in these properties became more prominent in the concrete samples aggregated with larger rubber aggregate. These altered characteristics are attributed to aggregated rubber because of its fiber structure, which gives the concrete its flexibility and capacity to take in strokes. This increase in elasticity and ability to absorb energy greatly reduces the damage incurred by vehicles colliding with parapets in highway barriers. With this in mind, vehicle impacts taking place with this concrete barriers have been approached as collision problems.

Collision Problem

The impact effects created by vehicles colliding with rubberized concretes will be examined as a dynamic problem, and this has been undertaken for examination using comparative analysis of

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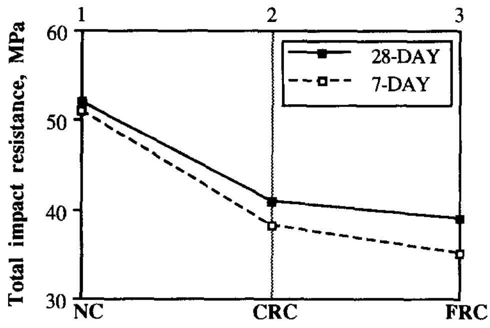

FIG. 1.
Change of the total impact resistance with regard to concrete types.

the collision results. The effects that arise due to a 1-ton vehicle colliding with highway parapets at a rate of 60 km/h were compared with the results of the striking experiments performed. For the purpose of analysis, collision is handled as an elastokinetic problem. Here, dynamic effects resulting from the collision of a vehicle with concrete will be determined by examining the static effects. The local transformations occurring at impact points for all substances are accepted as being plastic in nature. Thus, such a collision is referred to as a plastic collision, assuming that striking masses are moving at the same speed. Transformation of the kinetic energy, possessed by the vehicle at the point of impact, results in the deformation of the concrete. If the vehicle had affected concrete in a static manner, δ_{static} deformation would have occurred. The dynamic deformation has been calculated using the equations below. The variables used in solving these equations are represented as h height of the falling mass, E elasticity modulus of the concrete, A area of the impact surface, L length of the stationary mass, V volume of specimen, G weight of the falling mass, η coefficient specifying energy loss, Φ dynamic coefficient, δ_{static} static displacement at the point of impact, $\delta_{dynamic}$ dynamic displacement, $\sigma_{dynamic}$ dynamic stress, m mass of the stationary component, and M mass of the striking component.

$$\eta = 11/(1 + (m/M)) \tag{1}$$

$$\Phi = 1 + (1 + \eta 2h/\delta_{static})^{1/2} \tag{2}$$

If the vehicle had affected concrete in a static manner:

$$\delta_{static} = GL/EA \tag{3}$$

This would have occurred:

$$\delta_{dynamic} = \Phi\ \delta_{static} \text{ and } \sigma_{dynamic} = \Phi\ \sigma_{static} \tag{4}$$

With these equations, dynamic displacement and stresses have been calculated (9).

Experimental Study

Specimens of rubberized concrete were prepared using pieces of discarded tires cut into different dimensions. Type II cement used in these concrete specimens had a specific gravity of 3.15 kg/m^3 and a 28-day compressive strength of 382 kg/cm^2. The rubber pieces used had

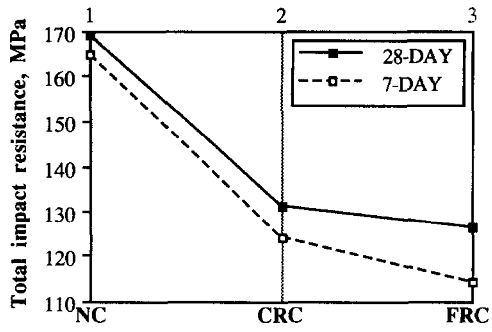

FIG. 2.
Total impact resistances obtained, dynamic with regard to concrete types.

diameters of 1.7 and 2.2 mm, respectively, and their density was 1.025 kg/dm^3 and were added into the mixture, replacing coarse aggregate materials at their respective rates of 15, 30, and 45%. The other materials used in concrete were limestone and river sand. After preparation of the specimens (150 mm in diameter and 300 mm in height), impact tests were carried out in order to measure the relationship between total impact resistance and impact effects. The experiments were done using a 65-kg mass dropped from a height of 650 mm after which it impacted with concrete or steel specimens. The mass was dropped several times until the concrete became broken due to impact affects.

Analysis of the Experimental Results

The collision test carried out by dropping a 65-kg mass from a 650-mm height, was done to determine dynamic characteristics of rubberized concrete in comparison to normal concrete and steel. The values obtained and the calculated results pertaining to dynamic effects are shown in Table 1, for rubberized concrete, normal concrete, and steel.

$$\sigma_{\text{static}} = Mg/A = 65 \times 10/17700 = 0.037 \text{ MPa} \quad (A = 17700 \text{ mm}^2)$$

$$\sigma_{\text{collision}} = Mgh/V = 65 \times 10 \times 650/5301.4 = 0.0797 \text{ MPa} \quad (\text{V} = 5301.4 \text{ cm}^3)$$

$$\sigma_{\text{total}} = \sigma_{\text{dynamic}} + \sigma_{\text{collision}}$$

By examining the total values of both dynamic and static effects, it was concluded that barriers made with rubberized concrete, possessing low elasticity modulus, reduced the impact damages resulting from collision. Furthermore, although normal concrete and steel specimens, demonstrating high elasticity modulus, are known to have high impact resistance, we cannot claim that they will diminish impact damages as effectively as rubberized concretes when they are used in highway parapets. Because rubberized concrete absorbs plastic energy easily, it is able to partially extinguish it and apply more displacement. Finally, the damages incurred by the striking substance reach a minimum when colliding with rubberized concrete. By comparing total σ values for steel with normal concrete, fine ground, and coarse ground rubberized concretes, aged for both 7 and 28 days, the following rates were obtained:

TABLE 1
Dynamic values from impact experiments

Concrete Type	Day	$E_{avg.}$ MPa	δ_{static} cm	η	ϕ	$\delta_{dynamic}$ cm	σ_{static} MPa	$\sigma_{dynamic}$ MPa	$\sigma_{collision}$ MPa	σ_{total} MPa
NC	7	19091	5.77×10^{-5}	0.838	1375	0.079	0.037	50.875	0.0797	50.955
	28	20000	5.51×10^{-5}	0.837	1406	0.077	0.037	52.022	0.0797	52.102
FRC	7	9020	1.22×10^{-4}	0.843	948	0.116	0.037	35.076	0.0797	35.156
	28	11121	9.9×10^{-5}	0.841	1052	0.104	0.037	38.924	0.0797	39.004
CRC	7	10690	1.03×10^{-4}	0.842	1032	0.106	0.037	38.180	0.0797	38.260
	28	11989	9.19×10^{-6}	0.841	1092	0.100	0.037	40.404	0.0797	40.484
STEEL		210000	5.25×10^{-6}	0.610	3887	0.020	0.037	143.82	0.0797	143.9

NC, normal concrete; FRC, fine rubberized concrete; CRC, coarse rubberized concrete.

7-day	28-day
$\sigma_{total\ NC}/\sigma_{total\ steel} = 50.955/143.9 = 0.35$	$\sigma_{total\ NC}/\sigma_{total\ steel} = 52.102/143.9 = 0.36$
$\sigma_{total\ FRC}/\sigma_{total\ steel} = 35.156/143.9 = 0.24$	$\sigma_{total\ FRC}/\sigma_{total\ steel} = 39.004/143.9 = 0.27$
$\sigma_{total\ CRC}/\sigma_{total\ steel} = 38.260/143.9 = 0.27$	$\sigma_{total\ CRC}/\sigma_{total\ steel} = 40.484/143.9 = 0.28$

When analyzing the rates given above, the smallest rates represent the least amount of damage following collision. In the second study, these results were examined and compared based on the determination of dynamic values and stresses created by a collision (10). This collision was caused by the impact of a 1-ton automobile, travelling at a speed of 60 km/h, with blocks (area and thickness are 1.5 m^2 and 10 cm, respectively) of normal concrete, rubberized concrete and steel. The dynamic values and stress calculated are given in Table 2.

The following rates were calculated by comparing total σ values:

7-day	28-day
$\sigma_{total\ NC}/\sigma_{total\ steel} = 164.89/429.96 = 0.38$	$\sigma_{total\ NC}/\sigma_{total\ steel} = 169.32/429.96 = 0.39$
$\sigma_{total\ FRC}/\sigma_{total\ steel} = 114.15/429.96 = 0.26$	$\sigma_{total\ FRC}/\sigma_{total\ steel} = 126.51/429.96 = 0.29$
$\sigma_{total\ CRC}/\sigma_{total\ steel} = 124.23/429.96 = 0.29$	$\sigma_{total\ CRC}/\sigma_{total\ steel} = 131.19/429.96 = 0.30$

TABLE 2
Impact stress and dynamic values from collision

Concrete Type	Day	$E_{avg.}$ MPa	δ_{static} cm	η	ϕ	$\delta_{dynamic}$ cm	σ_{static} MPa	$\sigma_{dynamic}$ MPa	$\sigma_{collision}$ MPa	σ_{total} MPa
NC	7	19091	3.49×10^{-6}	0.738	24469	0.0085	0.0067	163.95	0.943	164.89
	28	20000	3.30×10^{-6}	0.736	25131	0.083	0.0067	168.38	0.943	169.32
FRC	7	9020	7.39×10^{-6}	0.745	16896	0.125	0.0067	113.21	0.943	114.15
	28	11121	5.99×10^{-6}	0.743	18742	0.112	0.0067	125.57	0.943	126.51
CRC	7	10690	6.24×10^{-6}	0.746	18399	0.115	0.0067	123.28	0.943	124.22
	28	11989	5.56×10^{-6}	0.742	19440	0.108	0.0067	130.25	0.943	131.19
STEEL		210000	3.17×10^{-7}	0.459	64032	0.020	0.0067	429.0	0.943	429.96

TABLE 3
Cost analysis for C 30 fine ground limestone concrete

Day	Concrete Type	Elasticity Modulus MPa	η	σ_s	V m^3	Unit Cost Ratio	Cost Coeff.
28	NC	20000	0.839	24.25	0.024	1.05	0.025
	FRC15	12923	0.840	17.96	0.028	1.04	0.029
	FRC30	10500	0.845	13.77	0.039	1.02	0.040
	FRC45	9941	0.847	8.83	0.091	1.01	0.092
	CRC15	13770	0.841	18.33	0.029	1.03	0.030
	CRC30	11429	0.843	12.94	0.049	1.02	0.05
	CRC45	10769	0.845	11.58	0.057	1.00	0.057
7	NC	19091	0.839	16.53	0.050	1.05	0.053
	FRC15	10244	0.842	16.19	0.028	1.04	0.029
	FRC30	9618	0.846	7.17	0.133	1.02	0.136
	FRC45	7200	0.849	7.09	0.102	1.01	0.103
	CRC15	11250	0.842	8.87	0.101	1.03	0.104
	CRC30	11053	0.845	8.03	0.122	1.02	0.124
	CRC45	9767	0.846	5.81	0.206	1.00	0.20

Cost Analysis

In analyzing the calculations above, the smaller the rate, the greater the capacity to absorb energy. According to this, fine ground rubberized concrete would be the most appropriate substance for highway parapets, as it has the smallest rates. The minimum volume formula required was used for dimensioning with dynamic calculations in order to do a cost analysis. This formula was obtained by converting the energy from static loading to the elastic system into dynamic energy. Here, it was accepted that the elastic system showed resistance to impact, and this resistance was derived from the volume of the elastic system, rather than the cross section of it. According to this, the minimum volumes resistant to impact were determined using this formula:

$$V = 2\,E\bar{\omega}_o h/\alpha(\sigma_s)^2 \tag{5}$$

$$\sigma_s = \frac{\sigma_{max}}{1.5} \quad V = \frac{2E\bar{\omega}_0\eta}{\alpha\sigma^2} \tag{6}$$

Minimum volumes for impact resistance were calculated and are shown in Table 3. V, E, v_o (Mgh = 422,500 kgmm), η, α (=1), σ_s, and 1.5 are volume, elasticity modulus, energy at the time of impact, coefficient specifying the rate of energy loss coefficient for smoothness in terms of form, safety stress of the concrete, and coefficient of confidence, respectively. The costs calculated for minimum volumes in Table 3 reveal that the most economic material is FRC 15.

The costs were calculated for minimum values in Table 3 and found unit cost ratios by comparing each mixture's cost with each other. Then, unit cost coefficients were obtained in order to find the most economic solution, which is FRC 15.

Conclusion

The comparative analyses performed show that rubberized concretes are more suitable for use in places where no carrying function occurs. This is subject to impacts requiring voice insulation and when economic conditions are taken into account. As a result, it was determined that the cost of highway parapets manufactured with FRC 15 are more economical than those made with normal concrete. Furthermore, having considered the elasticity of FRC 15, we can also state that it is more reliable.

References

1. F. Rad, New Horizons in Construction Materials, pp. 87–292, 1976.
2. İ.B. Topçu and Y. Özçeliörs, Akdeniz University, Isparta Eng. Fac., 7th Eng. Week. Publ., Isparta, Turkey, 1991 (in Turkish).
3. K. Aydoğmus, Dynamic Properties of Rubberized Concrete, B.S. Thesis, Anadolu Univ., Eskişehir, Turkey 1993 (in Turkish).
4. N.N. Eldin and A. B. Senouci, J. Mat. Civ. Engng. 5, 478–497 (1993).
5. M.S. Acar, J. Prefabrication Union 1, 15–19 (1987).
6. D. Dölcel and D.N. Dölcel, J. Prefabrication Union 3, 1–17 (1989).
7. İ.B. Topçu, Symp. of Using Industrial Wastes in Construction Sector, T.M.M.O.B., Cham. of Civ. Eng., Branch of Ankara, Turkey, 39–352, 1993 (in Turkish).
8. İ.B. Topçu, Cem. Concr. Res. 25, 304–310 (1995)
9. M. İnan, Strength of Materials, 130, İİ.T.Ü., İstanbul, Turkey, 1983
10. U.N. Gandhi and S.J. Hu, Int. J. Impact Engng. 16, 95–118 (1995).