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Concrete under biaxial dynamic compressive loading

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Abstract

A concrete type C20/25 was examined under biaxial dynamic compressive loading with several stress ratios and two different loading rates (75 and 150 1/s). The question to be answered is, if the two strength enhancing effects of biaxial compressive loading and elevated strain rate overlay under this combined loading condition. For these experiments a unique biaxial Split-Hopkinson-Pressure-Bar, developed at TechnischeUniversität Dresden, was used to load the cubic specimen with two compression pulses from two perpendicular directions, simultaneously. That means the pulses have to reach the specimen within a time span of maximum 25 µs to achieve a rising stress level in both spatial directions in the specimen. For comparison, further static uni- and biaxial trials, static-dynamic biaxial trials and dynamic uniaxial trials were conducted. After the trials, the particles of the fragmented specimens were analysed in size and shape. The results show clearly that the two examined strength increasing effects superimpose in case of a combined biaxial dynamic compressive loading, but not completely. Therefore the influence factor of each single effect was analysed, depending on the stress ratio and the strain rate. For the considered range of high loading velocities, the strain rate effect has the main influence on the strength enhancement. This effect is decreasing with a growing stress ratio, here the biaxiality gains more influence but still remains behind the strain rate effect.

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Keywords: Split-Hopkinson-Bar; SHB; dynamic loading; biaxial loading; compressive loading; concrete; strain rate; experimental results

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1. Introduction

1.1. Motivation

The safety of our built environment is one of the most important tasks for centuries and even more in our times today. The Presidential Proclamation of Barack Obama from 29th April 2016, which declares the month of May 2016 to the month of national building safety with the request "Maintaining the safety and resilience of our homes and buildings is imperative" [1] shows the importance of this topic. This should be a motivation for everyone and in particular for the responsible engineers and scientists.

1.2. Short summary of knowledge

As it's known from several researches and publications in the literature, the compressive strength of concrete depends on several influences like the specimen geometry, the restrain of the lateral deformation of the loaded surface or the concrete's water saturation. This paper is about the influencing parameters rate and multiaxiality of the compressive loading. It aims to find if the two strength enhancing effects of dynamic compressive loading and biaxial compressive loading of a concrete specimen superimpose. Each of these influences were investigated very well separately within the last decades. But there are only a view publications know about the combined influence of a multiaxial dynamic compressive loading on concrete.

In 1964, Lundeen published the first results for a combined multiaxial dynamic loading of concrete [2]. He used a triaxial cell to apply a static radial pressure on the cylindrical specimen (σ_2=σ_3). Then the dynamic loading in the longitudinal direction of the cylinder (σ_1) was induced with a gas-operated impact machine. One of the main results was that the ratio of the dynamic strength to the static strength in σ_1 direction for radial pressures of 0.00, 1.72 and 3.45 N/mm² was approximately constant 1.37 for strain rates in the range of 5.6 to 10.3 1/s. Further dynamic trials in triaxial cells with a lateral static preloading and higher strain rates in longitudinal direction were conducted by Malvern and Jenkins [3] and Gary and Bailly [4]. Both researcher groups came to the result that an increasing confining pressure leads to higher compressive static and dynamic strengths.

Another technique to achieve a dynamic multiaxial state of stress is to confine the specimen by a rigid metal collar, which leads to a multiaxial state of stress due to the confined lateral expansion. Tests with this principle were conducted with a wide variety of measuring techniques and published results. So it could not be found a proper base for an overall comparison, so the presentation and comparison of this group is omitted here.

The third and most rare testing principle is to load the sample dynamically simultaneous in two or three spatial directions. The first results of triaxial dynamic loading tests were published by Gran et al. [5] in 1989 who carried out trials in the so called "4-kbar Dynamic Triaxial Loader", which is driven by explosive gases in two explosive chambers. Only 13 tests were conducted with different strain rates (0.5 to 10 1/s) and dynamic radial pressures (10 to 97 N/mm²). Much more systematic data are available from a group of researchers from the Dalian University of Technology who published their results in [6, 7, 8, 9] which includes biaxial compressive trials in static-dynamic and dynamic-dynamic configuration. The results in the four references were obtained in the same servo-hydraulic testing machine with the same specimen geometry (100 mm cube) and the same boundary conditions. So, all the results can be compared. The researchers conducted experiments with strain rates of 10^{-5}, 10^{-4}, 10^{-3} and 10^{-2} 1/s with confining pressures in the range of 3 to 30 N/mm² at two types of concrete with a static compressive strength of approximately 10 and 20 N/mm². Finally they draw the conclusion that the uniaxial and biaxial compressive strengths increase with increasing strain rate but with higher confining pressures the rate sensitivity decreases. In the examined range of medium strain rates, the increasing level of lateral pressure has a greater influence on the concrete strength than the strain rate. But there are no results for this type of tests with strain rates higher than 1 1/s.

This lack of knowledge about the concrete behaviour under biaxial dynamic loading for strain rates higher than 1 1/s was the motivation to develop a testing facility for this kind of trials – a biaxial Split-Hopkinson-Bar (SHB) – at the Institute of Concrete Structures at Technische Universität Dresden. The procedure of testing and the newest results for the biaxial dynamic strength of a concrete, type C20/25, are presented in this paper. To compare influence of multiaxial loading and dynamic loading both, uniaxial and biaxial tests were conducted under static and dynamic loading conditions.