HIGH TEMPERATURE TRIAXIAL-TORSIONAL TESTING MACHINE FOR CONCRETE AND ROCK

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Abstract. The purpose and design of a novel high-temperature triaxial-torsional testing machine for concrete and rock is described. The temperature range is up to 600°C, the maximum axial load is 5 MN, the maximum confining pressure is 140MPa and the maximum torque is 5555 NM. The testing chamber is cylindrical with a diameter 241 mm and length 686 mm. The machine will be used for testing concrete under conditions of nuclear reactor accidents, as well as for the development of general constitutive relations for solid or cracked concrete and rock.

Why Large Specimens?

The typical test specimens will be solid or hollow cylinders of 150 mm to 200 mm diameter and 300 mm length for concrete. Although this is a standard-size specimen, it is nevertheless quite large for the loading conditions used. The previous triaxial testing for portland cement concretes under triaxial loading and temperatures over 100°C has been carried out on small specimens of 15 mm diameter [Bažant, Kim, Meiri, 1979]. Thus, compared to the existing test devices, the new machine will allow a tremendous increase in size, at approximately 100 - times higher cost.

The increase in size is dictated by the need of using specimens with a realistic aggregate size (up to 30 mm), and eventually also with reinforcement or with cracks. Still larger specimens would of course be desirable to better simulate the conditions in a massive concrete wall of several meters in thickness. Nevertheless, although the effects of statistical heterogeneity in these specimens are larger than they would be for more massive specimens, this size does allow one to observe the true nonlinear behavior and fracture response of concrete, which is rather different from that of mortars (concrete with small aggregate) or neat cement pastes.

Another reason for larger size of the specimens is presented when deformation under simultaneous drying or moisture movement is to be observed. For very small specimens used so far the diffusion process of drying leads to drying times that are unrealistically short compared to creep test durations of interest.

Why High Temperature?

Although concrete reactor vessels and containments are in present designs kept cool (under 100°C), certain hypothetical (and highly unlikely) core-disruptive accidents in fast breeder reactors involve exposures of concrete to temperatures up to 600°C. A further need exists for studying conditions of fire exposure, as well as novel designs of chemical technology vessels (e.g., concrete vessels for coal-gassification).

It is well known that the inelastic deformations are generally rather sensitive to temperature, but the effect of temperature on the response of interlocked rough cracks or rock joints to shearing has not been established. It is not unlikely that a temperature increase would make the asperities more ductile (plastic or viscoplastic).

Why Torsional Loading?

The need for triaxial loading of concrete as well as rock specimens has been accepted for a long time and strength under combined axial-torsional loading was measured by many investigators [e.g., Bresler and Pister, 1958; Handin, et al 1967; Christensen, et al 1973 and 1974]. Completely general triaxial stresses have recently been also produced in cubic triaxial devices [e.g., Kupter and Gerstle, 1973]. In this light it might seem that a torsional loading capability is superfluous.

This is not so, however, because the loading history, i.e., the stress and strain path in the stress or strain space, profoundly affects the response of concrete as well as rock. The basic feature which is permitted by a triaxial device with torsional loading is that it allows loading histories in which the principal stress directions rotate during the loading process. Such loading histories are impossible with the conventional cylindrical or cubical triaxial devices.

The rotation of principal stress axes during the deformation process brings into play the stress-induced anisotropy of the material caused by previous loading. It allows one to study the incremental stiffness of the material for stress increments which are tangential to the current loading surface (in the sense of plastic potential). These aspects have recently been recognized as essential for the development of general constitutive relations [cf. e.g., Bažant, 1980]. They are particularly important for analyses of failure, which often happens in a deformation mode in which the principal strain directions rotate. This is characteristic, e.g., of the behavior of the material within a shear band inclined relative to the maximum compressive stress.

Another need for torsional loading exists when a material intersected by rough interlocked cracks or joints (in case of rock) is considered. The new machine allows one to test a concrete or rock cylinder with a transverse crack or joint which is subjected to controlled normal stress across the crack, controlled confining stress on the material, or controlled shear and normal relative displacements across the crack or joint. Thus the frictional and dilatant aspects of the deformation on the cracks or joints can be deter-

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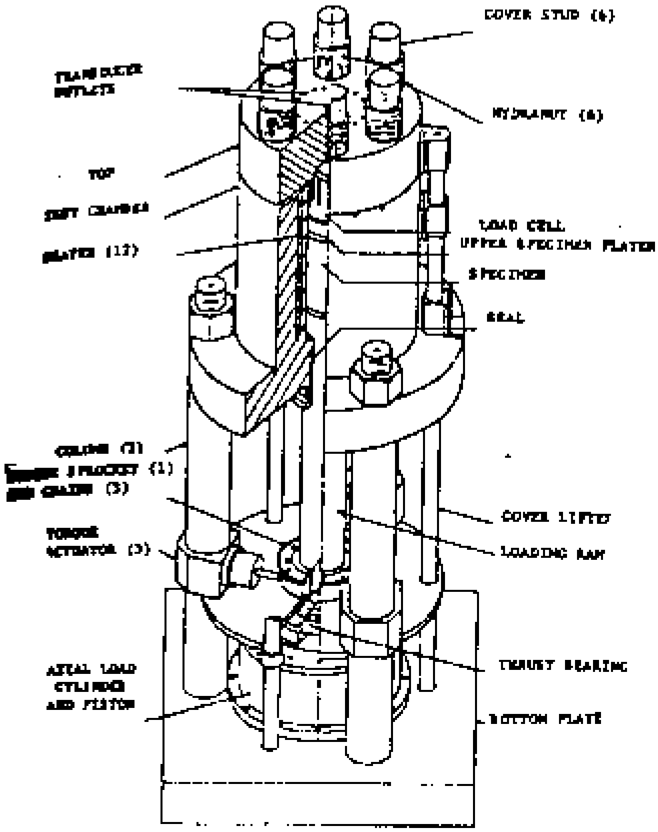

Fig. 1 General View of the Machine with Radial **Section**.

mined. Compared to the direct shear test specimens [Kutter, 1971] the use of torsional loading has some important advantages, namely that the relative shear displacement across the crack is uniform along the circumference and is known at each point of the crack plane if the relative rotation of the opposite surface of the crack is measured.

Construction and Capabilities of the New Machine

The lateral pressure on the test specimen can be provided either by gas or by water. Specimens can be either jacketed or exposed. Thus it is possible to test specimens in a sealed condition, drying, dried, or subjected to water which penetrates under pressure into the specimen. All these factors have a strong influence on the response. Furthermore, measurement of pore pressure and control of pore pressure within the specimen is possible.

Flat roughened file platens (without any circumferential grips) are normally used to transmit the torque into the specimen. If, however, the axial load is too small to provide sufficient friction, epoxy gluing is necessary. The lower platen contains a swivel socket to achieve good centricity of axial load. The swivel must be, however, blocked by a torque key when torsion is applied. Pore water can be injected into the specimen through the platens. To allow easy instrumentation of the specimen, hydraulic rams can lift the specimen and the top cover of the test chamber above the barrel section. The main top platen fasteners are tightened by being first hydraulically tensioned, after which the nut is tightened by hand. The machine height is 4.27 m.

The axial load, fluid pressure and torque are all servo-controlled. The torque is generated by three actuators (Fig. 1); a chain drive is used to allow large rotation. The actuators are arranted symmetrically, so as to make the lateral force resultant on the piston zero and thus minimize friction. The high-pressure low-friction seals of the chamber around the piston shaft consist of synthetic graphite (trade name Grafoil).

The axial force and the torque are measured inside the chamber by a single load cell. The strains of the specimen are measured by welded and encapsulated strain gages mounted on clamps or by variable inductance transducers (J-1 eddy current transducer). Carpenter A-286, a high chrome nickel alloy, and inconel 718 are used for critical parts of the test chamber exposed to high temperature. The chamber is insulated on the outside by a vacuum formed high alumina ceramic fiber material. Rapid cooling by flushing cold water through the chamber is possible. The test chamber is heated by cartridge-type heaters embedded in the wall.

The preceding paper by Hess [1980] may be consulted for more detail.

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