SHEARING VALUES OF STONE AND CONCRETE.*

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A very common failure of stone lintels is by shear —rupture in a slightly diagonal direction up from one of the points of support. It is not at all as uncommon as it should be for the seats of lintels, and similarly loaded corners of brickwork and concrete, to shear off, although the line of rupture is at a considerable angle with the direction of the stress. The seat of the proscenium arch girder of a well-known theatre some years ago sheared in this way and caused the girder to drop and wreck the roof, which was carried by it. Reinforced concrete girders were designed and built somewhat extensively before their tendency to fail by shear was generally recognized and treated with special reinforcement. There was considerable and sometimes acrimonious controversy in public print between engineers holding opposite views as to whether shear as such actually existed in the girders and caused the failures in question or not. And with the advent of light concrete arches the question of the need for adequate resistance to shearing forces in an arch ring becomes pertinent.

The substitution of one material for another, such as concrete for stone masonry, in any class of structure may not unreasonably be expected to develop some failure to make provision for stress of a kind that with a previous material has not required special provision. In the common type of stone arches any shearing stress that there may be is so low per unit of section, because of the great thickness of the haunches, that it is more than abundantly cared for; besides, the shearing value of any stone that will be regarded as good enough for an arch is quite high, compared with what is generally considered a safe compressive loading for stone masonry. Ordinary concrete, however, has a low shearing value, and the fact must have consideration in designing structures to be built of it.

The shearing failure of lintel seats and arch rings is of the character of the usual compressive failure of a concrete prism or short column—a diagonal shear at an angle of anywhere from 35 to 40 degrees with the direction of the force of compression, and it is characteristic of a material of low relative shearing value.

If, in addition to the direct compressive stress in such a prism or column, we apply force at one side deflecting the first force, unless the axis of the member be adjusted to coincide with the resultant of the two forces, the side force will constitute a true shear, and if it be applied at the point where the diagonal rupture would happen to occur from compression alone it must have the effect of lessening the resistance of the prism by both increasing the component and causing the rupture to become more nearly tensile in character. If we do, as we try to in an arch, correctly adjust the axis of the member to the change in direction of the force, the resultant force delivered to the abutment skewback is theoretically a simple direct compressive stress resisted by a bearing that should be normal to it; but in practice it is rarely quite normal, and never can be uniformly so, because of the change in position and direction of the line of pressure, due to the variation in temperature and loading. A rocking and bending motion is thus induced, and actual shearing stress is, therefore, clearly developed.

In certain recent tests of small-model concrete arches such of them as were loaded in a manner to preclude buckling from eccentricity of stress failed by shear, one wherein the depth of ring was made uniform throughout punching itself down between the abutments, the line of shear being inclined up from the edge of the skewback, the action appearing like shear in a simple beam or lintel. Exactly similar failure occurred in a number of specimen prisms made and loaded to imitate the same condition of stress. It would, therefore, seem that the fact of shearing action at the edge of an arch abutment is sufficiently established to command attention to it and require provision for it.

The compressive shear of the prism appears, by dividing the component along the line of rupture into the ruptured area, to show a unit shearing resistance of about four-tenths that of the unit direct compression. In a test for shearing value alone so high a result can be obtained only by some fanciful conditions of test that do not represent service. It is convenient to express the shearing value of concrete in terms of the compressive value, although there is not necessarily any relation between the two, for a prism might be made of flat plates not cemented together and yet develop very high compressive resistance without having any tensile or shearing strength. But if the pile be compressed at the same time by a direct pressure the friction between the plates will develop positive shearing resistance. This effect is supposed to obtain in ordinary concrete, but is evidently more than offset by the lessened resistance to the compressive stress. The problem, therefore, becomes somewhat complex. Records of tests of the shearing quality of concrete are somewhat meagre, and vary so widely that different investigators have evidently not only used widely different methods, but have varied ideas of what constitutes shear. Text books variously give the shearing value of cement mortar and concrete, one as low as 16 per cent., another as high as 104 per cent. of the compressive value, one experimenter using cylindrical specimens and shearing them like a pin in eyebars. Results obtained by tests can be intelligently used only with a clear knowledge of the exact circumstances, and always some arbitrary allowance must be made for what formerly was called personal equation, but clearly goes far beyond that.

It is very desirable that a designer should himself make the tests upon which he depends for his knowledge of the sustaining value of the material that he uses in important structures, for ideas develop under observation of the action of forces and the behavior of material.

The character of shearing failures indicates the manner in which shearing tests should be made. The line of least resistance should be sought and the testing force applied there. As the shearing value seems to bear a fairly close relation to the tensile strength, the line of rupture in a service failure is more or less diagonal. Tests made under fanciful conditions may be misleading. A shearing test of a granular material like concrete, stone, brick or mortar should not be made as if it were of steel. Academic tests in general are liable to be more interesting than practical.

As a general proposition, a shearing test of concrete should have the cutting edges offset at least as much as the diameter of the largest particles of the aggregate in the specimen, and tests should record the facts of the amount of offset and thickness of specimen to give the angle of the line of rupture. Roughly, the nearer this line is to 90 degrees—that is, the closer the knives—the higher the result. As the inclination increases the resistance decreases, for the rupturing stress approaches tensile in character.

A large number of recent tests of concrete and stone and brick seem to fix the most desirable angle of shear for test at one in eight—the upper cutting edge set back from the lower one-eighth of the thickness of the specimen, and in the case of the concrete test this approximates the ratio between the thickness of the test piece and the diameter of the larger particles of the aggregates used in making them. Greater offset was found to be liable to cause failure by bending rather than by shear. The results obtained varied about as widely in each class as those of compressive and tensile tests of

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