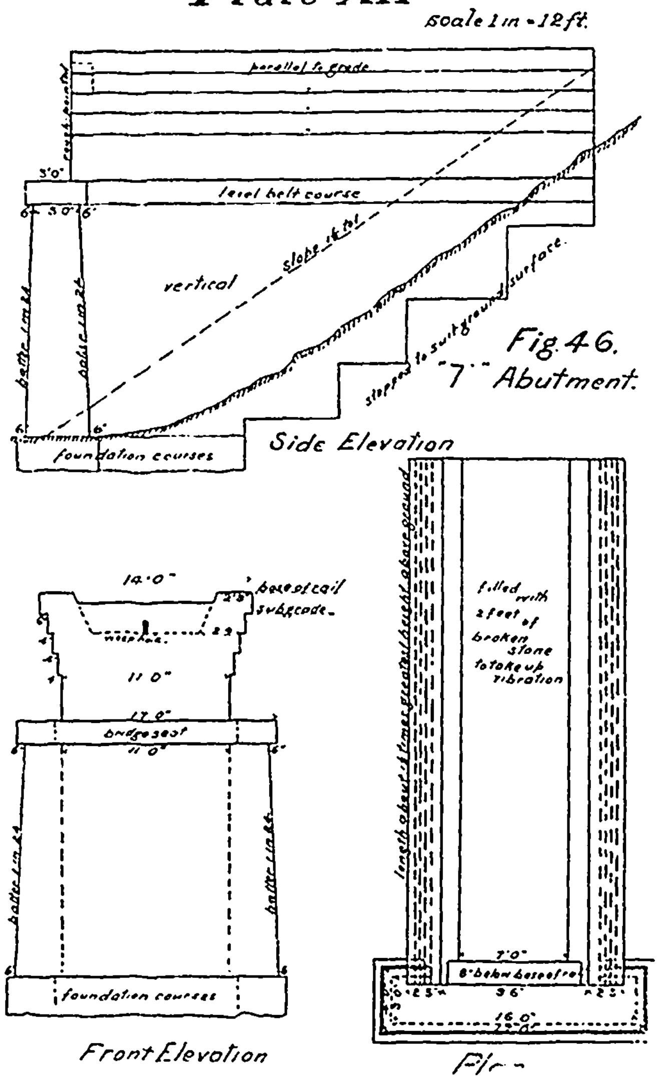
ments with an exterior covering of longitudinal strips or timbers is used, until the keystones are inserted. They should be designed for the weights they are to carry and rigidly supported so that absolutely no settlement may occur. But at the same time each point of support should be either on wedges that can be slackened, or on cylinders filled with sand that can be drawn off gradually at the proper time. Soon after the keystones have been inserted the easing process should begin and should be in two stages. First, a slight easement sufficient to bring each joint under pressure, and in a week or two later when the mortar has become hard they may be gradually and uniformly lowered so as to throw all the load on the arch. Figures 41, 42, 43 and 36 illustrate types of centres, and the wedges are shown in Fig. 41.

Specification for Stone Arch Culvert Masonry.—It will be laid in cement mortar of approved quality, the

Plate XII



arch sheeting stones shall be of the length, depth and thickness shown on the plans, or such as the engineer shall prescribe, and shall be cut accurately on their intrados, beds and joints according to template, and shall be carefully laid with a thoroughly good bond lengthwise of the arch. The face ring stones shall be left rough on the face, except a $1\frac{1}{2}$ inch intrados draft, and no projection allowed of more than 3 inches from such draft. The spandrel filling shall be rough rubble similar to good box culvert masonry, but of good bed, bond and quality of stone. The abutments and wings, or head walls and parapet walls shall be either first-class or second-class bridge masonry as the engineer may direct. (See bridge masonry specifications.

The cost of arch culvert masonry will vary with the price of stone cutting, price of brick and labor, but may be taken ordinarily at $6 per cubic yard for rubble arches; $8 to $10 for second-class arch abutments; $10 to $14 for cut arch sheeting; $8 per cubic yard for ordinary brick arches.

The quantity of masonry in arches of even the same span and rise will be so entirely dependent on the height of abutments and depth of foundations that no table will be given. The tables given for purposes of approximate estimates in Trautwine "Engineer's Pocket Book," will be found very useful.

ARTICLE 20.—ARCHES.

So much has been written on this subject and the design of large arches for rivers or roadways, or for carrying roads over railways, etc., has received such elaborate study, that it is outside the range of this work, but types of such structures are given on Plate XI., and many of the remarks on arch culverts will apply to the larger structures with even greater emphasis, (*e.g.*), the importance of immovable foundations, and taking care of the line of pressures below the haunch and in the abutments, for this purpose the abutments are often built with the beds inclined to the horizontal and nearly at right angles to the pressure, see Fig. 36, and in any case should never be further from such a right angle than the angle of friction of stone on mortar.

Whether in a given case an arch or two abutments and a plate girder span will be preferable, depends on the depth of the bank and width of stream, as far as economy is concerned, but other considerations are the greater durability and safety of an arch, its finer appearance and an absence of repairs.

The use of concrete with steel rods or wire embedded in the tension side of the arch sheeting has lately come into use for arches of small rise, especially where rolling loads tend to distort the arch, the possibility of this form of construction lies in the fact that steel and concrete have almost identical co-efficients of expansion.

ARTICLE 21.—BRIDGE SUBSTRUCTURES.

As the size of waterway increases, the cost of an arch soon becomes excessive, owing to the heavy abutments necessary for arches of long span and small height. On the other hand the cost of bridge abutments increases very rapidly with the depth of bank, so that we have two limiting features to guide us in the selection of the style of structure most suitable for a given small stream or creek, *e.g.*, with a 30-foot span and embankment 30 feet high the costs about equal each other. But whenever the arch does not cost appreciably more than the open span it should be selected, owing to the absence of floor repairs and to increased safety given. It must be remembered that the addition of a solid buckleplate floor and ballast to a plate girder will, however, make it practically safe and almost eliminate repairs.

When the stream to be crossed is of considerable magnitude the question of span lengths will be the first one to decide upon, which must be done with due regard to the probable life of iron work and the cost of replacing and painting it, as well as to the total present minimum cost of structure.

The approximate minimum cost of structure is obtained when the cost of the trusses, not including the floor system, is equal to the cost of the masonry, which should include the cost of foundations, etc., but exclude the cost of those portions of abutments of which the function is to retain the earthwork and not to support the bridge, *i.e.*, the wings, etc; but it is usually safe to arrange the spans so that the