HISTORICAL DEVELOPMENT

The stone arch bridge represents one of the earliest recorded advances in bridge building, illustrating the movement from simple beam spans to use of the structural arch form to better support loads. Engineering historians have traced the first functional precursors of stone arch bridges to the so-called corbelled arch, utilized in ancient cultures. The corbelled arch consists of masonry blocks built over a wall opening by uniformly advancing courses from each side until they meet at a midpoint. No actual arch action is produced by this design, also often called a false arch (Pennsylvania Historical and Museum Commission, and Pennsylvania Department of Transportation 1986:A-5).

Since a true arch cannot support itself until the keystone is properly in place, the construction of stone arches required temporary support of the entire structure on falsework, usually composed of a scaffolded timber framework. Stone arch construction utilizing circular arches with keystones, and falsework during construction, was perfected by the ancient Romans, and the basic, necessary technology thereafter remained largely unchanged for two thousand years. Improvements between Roman times and the seventeenth century primarily consisted of efforts to achieve a greater span-to-rise ratio (that of the typical circular Roman arch was 2:1); for nearly 400 years after its 1345 construction, Florence's Ponte Vecchio with its "flat" (high span-to-rise ratio) trio of arches held the record for highest span-to-rise ratio (Lay 1992:267-268).

Coming from a tradition of craftsman design, the stone arch bridge owed its remarkable historical persistence to its load-carrying strength, its relatively simple construction technique, and its long life (Figure 7). The stones utilized in a stone arch bridge may consist of rubble masonry (rough unfinished and untooled stones), squared masonry (stones which have been tooled to a rectangular shape and roughly finished), and ashlar masonry (squared stones given a further tooling to a more refined finish). Construction of the substructure (piers and abutments from which the arch is said to "spring") was first accomplished, followed by the initial building of the "arch ring" (the basic ring composed of adjacent, usually wedge-shaped stones, or voussoirs, arranged in a radiating circle or ellipse) on the temporary system of wood falsework. With the arch rings in place across the intended width of a span (the rings together comprising the arch "barrel"), the remainder of the structure, including spandrel walls built on the arch at its outermost edges, could then be erected. Fill composed of dry earth or ballast was usually consolidated on top of the arch barrel for stability and was contained within the solid spandrel walls (P.A.C. Spero & Company 1991:13-14).

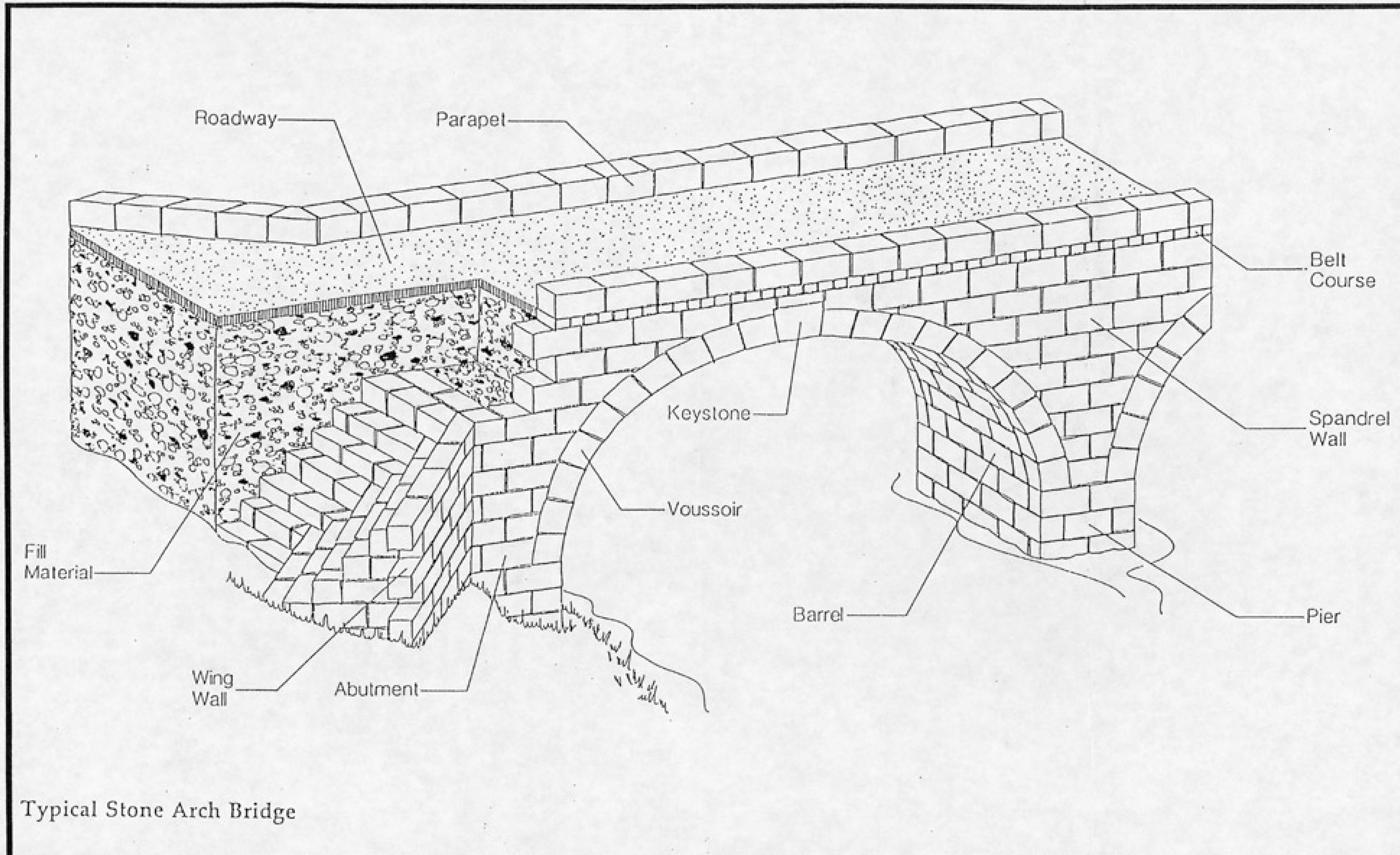

FIGURE 7: Typical Stone Arch Bridge

SOURCE: Pennsylvania Historical and Museum Commission and Pennsylvania Department of Transportation 1986

Arch bridges constructed of stone have included small bridges and culverts, as well as larger and longer multiple-span viaducts and aqueducts. Perhaps because the technology of arch construction was received rather than invented in the United States, bridge historian J.A.L. Waddell noted in his 1916 *Bridge Engineering* that "stone arch bridges have played a very small part in bridge evolution in America" (Waddell 1916:28). More recently, Carl Condit found that arch bridges of stone were "extremely rare" in the American colonies and that hardly any evidence of seventeenth century stone arch bridges existed (P.A.C. Spero & Company 1991:13). Legislation of the colonial period has survived indicating that colonial authorities (including Maryland's General Assembly of 1699) encouraged "good and substantial" bridges, but these may well have generally been of timber, a more readily available and less costly material than building stone in many parts of colonial America. The earliest extant datable examples of stone arch bridges in the United States are the Frankford Avenue Bridge, a three-span bridge constructed in 1697 on the King's Highway over Pennypack Creek near Philadelphia, and the Choate Bridge, a two-span structure built in 1764 at Ipswich, Massachusetts (Pennsylvania Historical and Museum Commission, and Pennsylvania Department of Transportation 1986:43; DeLony 1993:5).

Beginning in the late eighteenth century and continuing through much of the nineteenth century, the construction of stone arch bridges in the United States was given impetus by the internal improvements movement that spawned such ambitious engineering projects as turnpikes, canals, railroads, and water supply systems for rapidly growing cities. Turnpiking an existing road or properly building a new turnpike included plans for reliable stream and river crossings and a durable road surface of stone or gravel. Thus, the wealth of turnpikes built in the eastern United States between 1790 and 1840 often included improved bridges of stone to replace ferries or earlier simple wooden spans.

Canals required a variety of bridge structures, including short spans to carry the towpath from one side to the other at tight places, and culverts and aqueducts to take the canal itself over rivers and roads running transverse to its right-of-way. Lastly, the development and remarkable success of railroads in the nineteenth and early twentieth centuries inspired professional engineering interest in the design and erection of masonry structures that could effectively withstand the unprecedented heavy moving loads of locomotives and freight trains. Early large stone arch bridges constructed for railroad use, including Maryland's historic Carrollton and Thomas viaducts, dramatically illustrated the great strength inherent in the arch form. So, too, did the humbler stone culverts, often constructed to standard plans by railroads in the late nineteenth century.

The majority of surviving stone arch bridges and culverts in the United States are thus, historically linked to a turnpike, canal, or railroad of the 1800-1900 period (Plate 4). Private turnpike companies expended considerable capital building masonry arch bridges under the direction of experienced masons, but regular maintenance was not always adequately provided, and problems developed ranging from deterioration of parapet walls to bulging of spandrel walls due to accumulating moisture in the earth fill. Generally, the arches built for canal and railroad bridges were more likely than turnpike bridges to be designed by trained engineers. Stone masonry arch construction, frequently involving use of dressed masonry, was popular for railroads such as the B&O and the Pennsylvania Railroad even after the versatility of the metal truss bridge had been demonstrated in the latter half of the nineteenth century. Older turnpike bridges, however, attracted engineers' attention after the coming of the automobile and truck forced county, state, and municipal officials to provide for the heavy traffic demands of the twentieth century. Many such bridges were destroyed or seriously altered, but others continued in use or were bypassed and remained standing.

Though one of the most ancient bridge types, the stone arch bridge made a distinctly modern contribution to the development of concrete bridge technology. The stone masonry arch provided the precedent for arches constructed first in plain or unreinforced concrete, then later in concrete reinforced with metal sections, rods, or bars which resisted the tensile forces. Although few stone arches were built after the first several decades of the twentieth century, the persistence of the arch as built in the more plastic material, concrete, was due in large measure to the demonstrated advantages of stone masonry construction, as shown in numerous turnpike bridges and railroad spans.