Structural experimentation: the lintel arch, corbel and tie in western Roman architecture

Janet DeLaine

Introduction

To talk about Roman architectural innovation is, usually, to talk about the 'concrete revolution' – the development of a vaulted concrete architecture based on the semi-circular arch, an architecture which gave us the Pantheon and the Basilica of Maxentius. The power of this revolution has naturally attracted the attention of scholars away from other areas of structural experimentation which, if less pervasive in their use and less glamorous in their application, are nevertheless just as revealing of the processes of architectural innovation. This paper will examine three such elements – the corbel, the lintel arch, and the metal tie-bar – which were developed in Rome and Italy in parallel with, but outside the normal parameters of, the concrete revolution. All were developed within the ashlar tradition, while their later manifestations are marked by a highly selective use of stone for its specific structural properties within the developed concrete convention.

A distinction must be made between invention, the discovery of a new process, and innovation, its widespread adoption (Renfrew 1978). The three innovations will be examined in terms of the factors which led to their adoption and the subsequent experimentation which gave them a secure place within the repertoire of western Roman architecture. The emphasis will be on the structural and constructional advantages, although aesthetic factors will also be taken into account. The structural analysis does not, of course, imply that Roman builders thought in terms of thrusts and tensions; rather it provides a way of predicting the likely behaviour of a structural element under given conditions, i.e. the kind of empirical data on which further experimentation must have been based.

The corbel

The invention

The corbel is simply a short cantilever, the principle of which is obvious to anyone building with blocks of any material, and was no doubt 'invented' independently by many cultures.

World Archaeology Volume 21 No. 3 Architectural Innovation

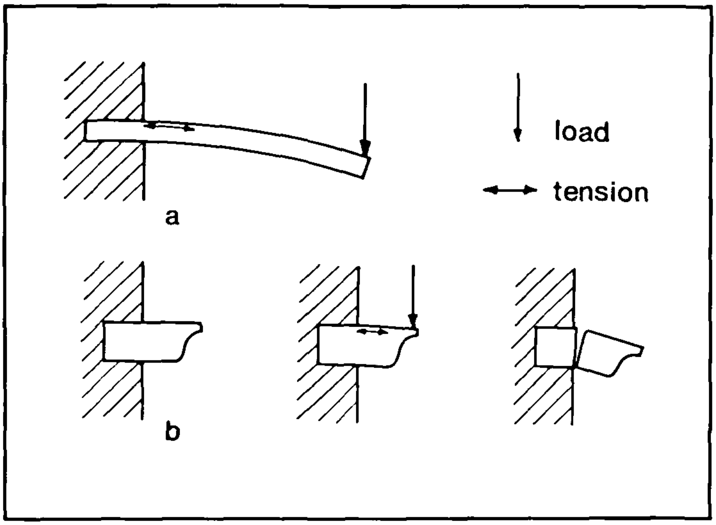

Figure 1 Structural behaviour of (a) wooden cantilever, (b) Roman type of stone corbel.

Corbelled arches and vaults were used from the earliest times throughout the Near East and the Mediterranean, and are found in Italy from the early Republican period (Blake 1947: 193–6). Other uses for the corbel, however, are relatively rare, although it is clear that the cantilever principle was known to Greek architects. It is the independent, short, deep corbel used as a projecting support which is the particularly Roman invention (Fig. 1).

The innovation

Probably the earliest use for this type of corbel was in the construction of Roman masonry arches, particularly for bridges and aqueducts, as in the Pont du Gard at Nîmes (Ward-Perkins 1981: 224–5). Long blocks were set into the masonry as headers at the springing or low on the haunches of the vault, so that the projecting ends helped support the centering, reducing the need for free-standing props; others projected from the faces of the piers. The aesthetics of such utilitarian structures seem sometimes to have allowed the corbels to be left after completion, making subsequent repairs easier. The device is a natural extension of ashlar construction. Heavy cornices, which also exploit the cantilever principle, are found at the springing of many monumental arches, including some of the earliest Republican gateways, and it would seem a short step from that to include cantilevers specifically for constructional purposes. In Rome at least, the practice must have been dependent on the introduction of travertine as a building material in the late second century BC, since the more common tufas are weak in tension (Blake 1947: 44–8); it is not, therefore, surprising to find the earliest dated example of such corbels at Rome in the Pons Fabricius of 62 BC (ibid.: 146).

Travertine corbels were also used for the same purpose in otherwise concrete constructions, and can still be seen built into the inner faces of the brick-faced piers of the Neronian Arcus Caelimontani (Blake 1959: 53) and the third-century Aqua Alexandrina in Rome (Adam 1984: Fig. 558). An extension of this idea is found in many insulae at both

Rome and Ostia, in columbaria, and in other utilitarian buildings of imperial date such as horrea, where travertine corbels provided the supports for the later insertion of timber mezzanine floors or walkways (Blake 1959; Blake and Bishop 1973: *passim*). More daringly, corbels were also used to support concrete vaults. The most common use in this case is for the arched balconies which are such a distinctive feature of many Roman insulae (Pl. 1) and other predominantly domestic or utilitarian façades (ibidem). Here the constructional innovation has for once a specific aesthetic effect, and the form of the corbel is based on the scroll modillion which was the particularly Roman contribution to the Corinthian order (Strong 1963). Finally, large travertine or marble corbels were used to support the corners of cross-vaults, effectively reducing the span of the vaults; examples occur in the main hall of Trajan's Markets and in the frigidarium of the Large Baths at Hadrian's Villa (Blake and Bishop 1973: 26, 255).

This highly selective use of stone, used not as a mere facing but for its structural properties within the developed concrete tradition, is itself an innovation which, as we have seen, has its origins in the Roman ashlar tradition. In theory, since both Roman

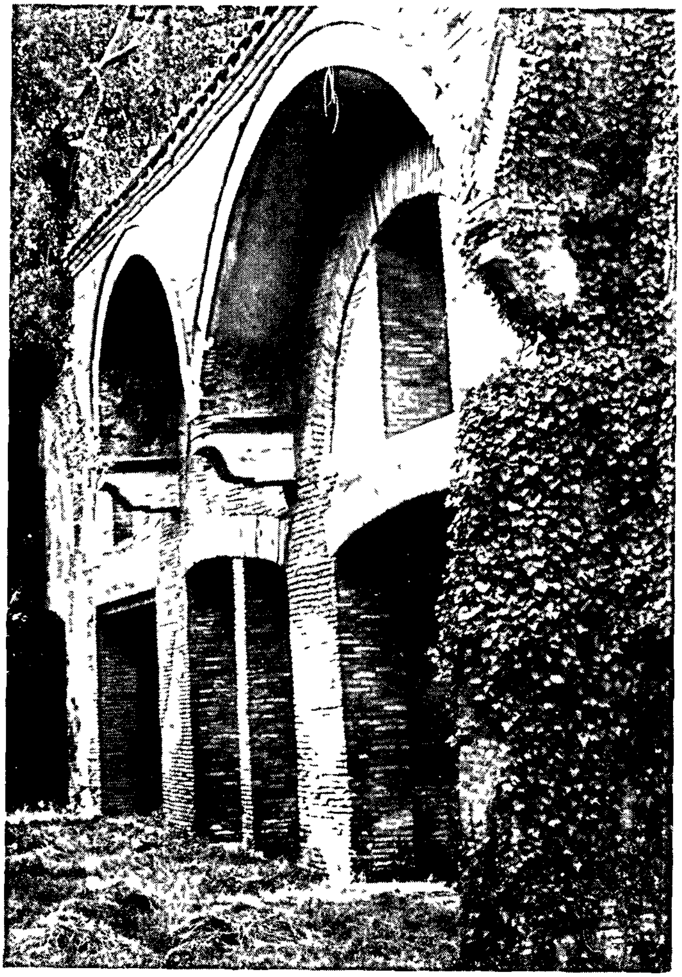

Plate 1 Corbelled balconies, Via dei Balconi, Ostia.

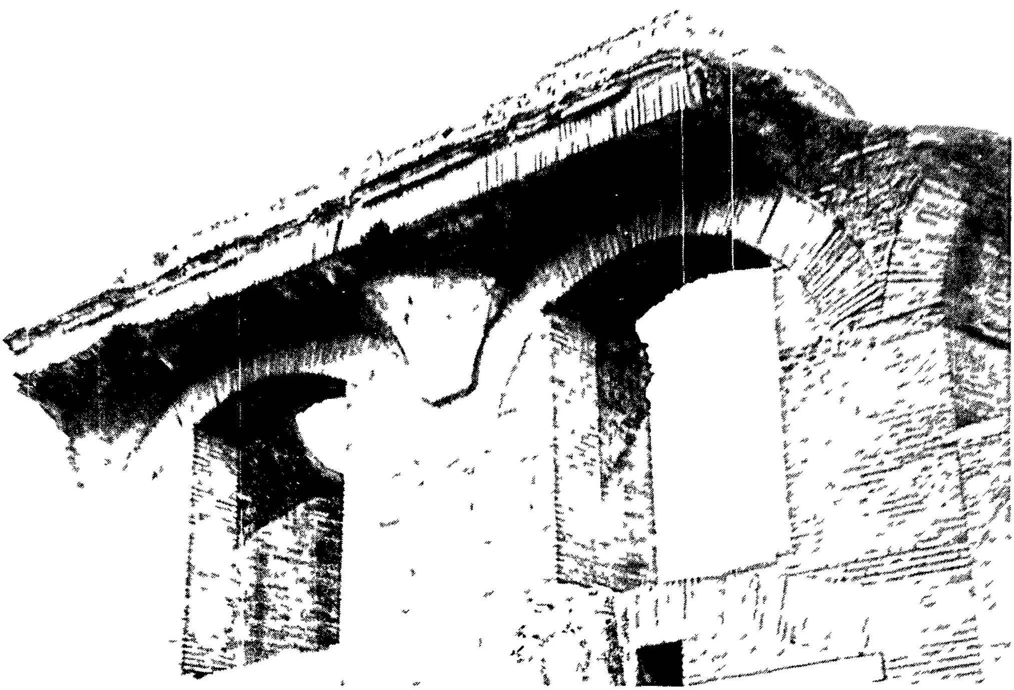

Plate 2 Vaulted balconies, Via di Diana, Ostia

concrete and the stronger kinds of stone can develop some resistance to tensile forces, the corbels themselves could have been made in concrete. Nevertheless, the alternative to a horizontally projecting stone corbel, used to support narrow balconies in Ostian insulae such as the Insula degli Aurighi, was a series of short vaults (Pl. 2). One explanation for this might be that the kind of formwork required for a short projecting member was alien to normal Roman procedure, but it is more likely to reflect the Roman builder's distrust of the material under tension. In other words, it is unlikely that the 'concrete revolution' *in itself* would have developed the corbel; rather it provided a medium conducive to experimentation with a device which had long before proved a valuable addition to the ashlar tradition.

The lintel arch

Structural behaviour

The stone lintel arch of wedge-shaped voussoirs is, structurally speaking, merely the flattest form of the more common semi-circular arch (Fig. 2). Jaques Heyman has shown that under ideal conditions, where there is no slipping between adjacent voussoirs and the abutments are sufficiently rigid, the lintel arch cannot collapse, whatever the loading (1966: 257–8; 1972). Nevertheless, because of its shape, the horizontal forces developed by a lintel arch are greater than those developed by an equivalent semi-circular arch of the same span, and the tendency for the abutments to give way is correspondingly greater and

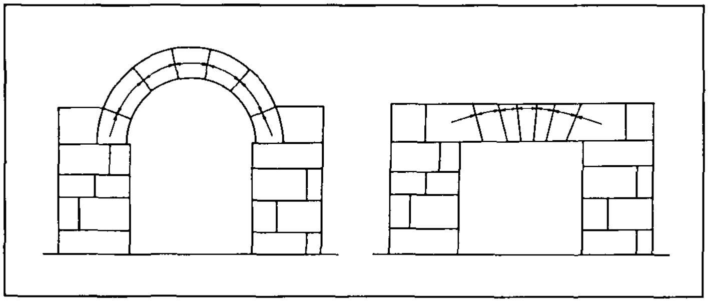

Figure 2 Resultant forces at the abutments of a semicircular arch and a lintel arch of the same span under self weight.

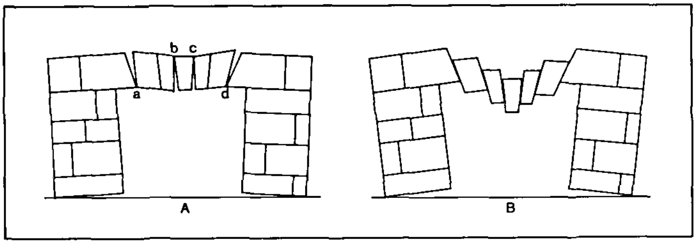

Figure 3 Structural behaviour of a lintel arch following movement of the abutments: (a) small movement, stable structure with harmless hinges created at points a, b, c, and d; (b) greater movement leading to slipping of voussoirs relative to one another.

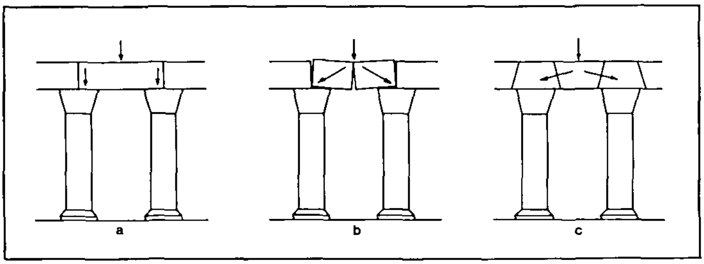

Figure 4 Structural behaviour of a monolithic lintel acting (a) as a beam and (b) as a simple lintel arch when cracked, and a comparable lintel arch (c).

might lead ultimately to collapse of the arch (Fig. 3). When a monolithic lintel (Fig. 4) cracks at the centre under load, it acts in a similar way to a lintel arch, and will also be stable provided the abutments remain sufficiently rigid. The advantage of cutting a lintel into voussoirs is that it anticipates any failure, avoiding visually worrying cracks and providing a predetermined and thus much more predictable structural system. If we now turn to concrete construction, the lintel arches appear to be made of voussoirs, but these 'voussoirs' do not all necessarily pass through the full thickness of the wall (Pl. 3), and the arch acts more as a weak stone lintel; failure will occur as often through the 'voussoirs' as through the mortar. Since the 'ends' of the 'lintel' are continuous with the supporting wall, the resultant failure will be at the supports as well as at the centre (Fig. 5).

The invention

Although the lintel arch was used in the mud-brick architecture of the Near East as early as the second millennium BC (p. 400), it does not seem to have been adopted into Greek

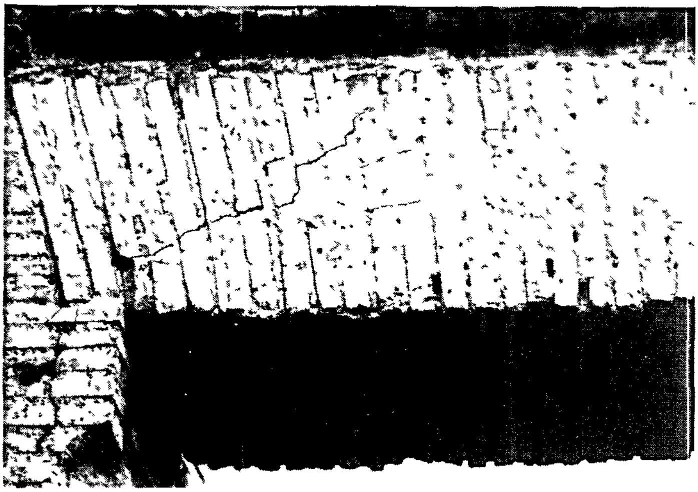

Plate 3 Concrete lintel arch, Ostia.

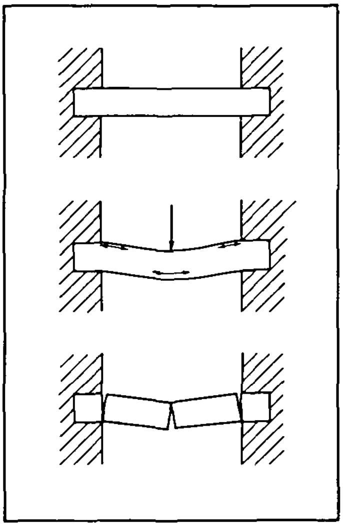

Figure 5 Structural behaviour of fixed ended beam

architecture along with the semi-circular voussoir arch in the late fourth century BC, and remained rare in the Hellenistic world (Boyd 1976: 70–1, 75–6). This is perhaps not surprising, for the Greeks used the semi-circular arch mainly as a stylistic device, over openings which, with few exceptions, could just as easily have been bridged using a simple lintel (ibid.: 104). Aesthetically, of course, the lintel arch and the true lintel are little different, so that the invention of the lintel arch should be dictated by structural and economic considerations. The existence of good supplies of strong limestones and marbles in the Greek world encouraged the use of simple stone lintels in most monumental building; even so the Greek use of stone is notoriously conservative. The normal upper limit for stone lintels in Greek stoae (Coulton 1976: 28–9) and in all but the largest Greek temples (Dinsmoor 1975: 337–40) appears to have been a clear span of roughly 3–3.5m, which keeps the tensile forces far below the theoretical strength of the stone used. For wider openings, various structural devices which increased the actual strength of the stone

Plate 4 Tufa lintel arch, Tabularium, Rome

beams were employed (Dorn and Jewett 1968; Coulton 1977: 145–51), or wooden lintels were used where aesthetically acceptable (Coulton 1976: 28–9).

The innovation

In Rome the tufas which formed the most common building material for monumental construction in the earlier Republican period were extremely weak in tension. Etruscan and early Roman wide span temples, like Greek stoae, had wooden architraves, and even in the second century BC Doric porticoes of the Forum and behind the Large Theatre at Pompeii, the tufa entablatures were carried on wooden beams (*Pompeii* 1981: 297–9; Adam 1984: fig. 467). It seems possible that the lintel arch was developed to meet the aesthetic ideals borrowed from traditional Greek architecture without having recourse to the stronger – and more expensive – limestones and marbles, or employing the less durable – and less prestigious – timber.

Some of the earliest surviving Roman stone lintel arches are found embedded in massive masonry walls to span doors or windows. The group of arches in the Tabularium in Rome (Delbrueck 1907: 26–46), usually dated to 76 BC, can be taken as representative; the assurance with which the technique is used – the arch over the southeast niche has an impressive span of 5.18m (Pl. 4) – suggests a long familiarity with this type of construction. This is the most stable position for a lintel arch, as the surrounding masonry prevents any shift in the abutments. Such use of lintel arches continued well into the imperial period, for example in the precinct wall of the Templum Pacis in Rome (Lugli 1957; Pl. LXXXVI, 3), or in the Porta Aurea of Diocletian's Palace at Split, where a joggle was cut in the voussoirs to eliminate any possibility of slipping (Hébrard and Zeiller 1912: Pl. facing p. 32).

The advantages in continuing to use lintel arches even where travertine and other good building stones were readily available are not difficult to imagine. Firstly, there was the possibility of spanning larger openings than were generally covered by simple stone lintels – 6.5m for the door of the Temple of Bacchus at Baalbek (Weigand 1923: Abb. 2) – a requirement dictated by the scale of much Roman architecture. More importantly, it was possible to span openings of considerable size even when large blocks of suitable stone were either unavailable, or not economically feasible. If the lintel arch required more time in construction and the use of full centering until the keystone was set in place, at least each individual element weighed less and was easier to quarry, transport and erect than the equivalent single lintel block.

Stone lintel arches are also occasionally found in situations where the only possible advantage appears to be constructional, rather than structural. The evidence is clearest for the lintel arches of the lowest range of shops in the main hemicycle of Trajan's Markets (Fig. 6; Pl. 5). Large travertine imposts were corbelled out from the wall both parallel and perpendicular to the opening, and the space filled with a single long voussoir, a device also found in the Colosseum (Durm 1905: Fig. 234) and in the theatre at Catania (Lugli 1957: Fig. 81). The lintel arches supported a brick-faced concrete curtain wall with a central window. This is the only place in the Markets where this construction is used, all other shops in the complex having true lintels, even though the spans are similar.

The explanation for this lies, I believe, in the construction process. It has long been recognised that the Markets, built as a series of terraces, act as a buttress for the cut in the Quirinal hill behind. The shops in question are at the base of the lowest terrace, and therefore represent an early stage of construction. The 'active' parts are the barrel-vaulted niches; the lintels and curtain walls are structurally extraneous. In addition, these elements project from the face of the wall, and would therefore be more open to accidental damage during construction of the floors above, as well as impeding the line of the scaffolding. The curtain walls were certainly added after the completion of the barrel-vaults, and it would seem that the reason for the lintel arch was that the central voussoir could also be added later, perhaps even as the last part of that level. This type of skeleton construction, although different in detail, has also been argued for parts of the Colosseum (Cozzo 1928: 211–23), and for the palaestra of the Baths of Caracalla and Diocletian (DeLaine 1985: 198–202).

A rather different use of the masonry lintel arch is in the entablature of the columnar orders. The earliest surviving example is in the Temple of Portunus in the Forum Boarium at Rome (Fiechter 1906: 239–40, af. VIII), usually dated to the early first century BC (Coarelli 1988: 320), where the frieze over the free standing columns of the porch is a true

Plate 5 Lintel arch construction, lower level hemicycle shops, Trajan's Markets, Rome

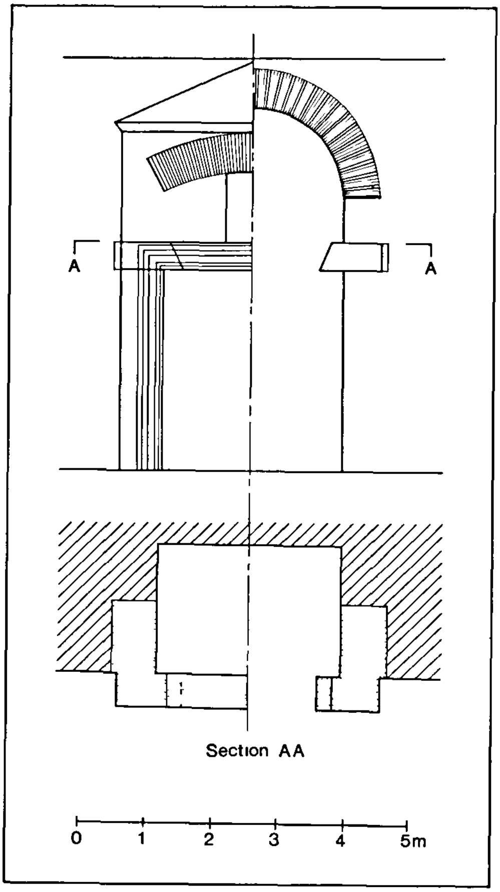

Figure 6 Lintel arch construction of lower level shops, Trajan's Markets, Rome

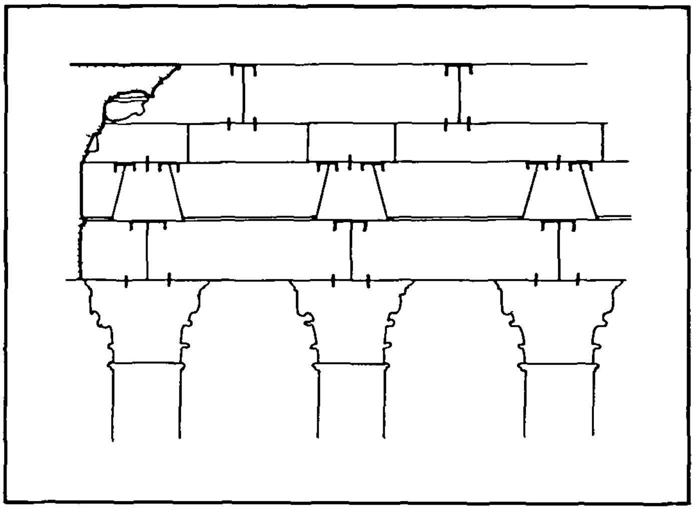

Figure 7 Relieving lintel arch construction, Temple of Castor, Rome (after Durm 1905: fig. 10).

lintel arch with impost blocks centred over the columns and the spaces filled in with a single wedge-shaped voussoir. This type of construction seems to have been particularly common in the Augustan period and is found, for example, in the Temple of Castor in the Roman Forum and in the Temple of Mars Ultor in the Forum of Augustus (Kockel 1983: 424, Abb. 2). Durm's drawing of the Temple of Castor (Fig. 7), confirmed by similar examples from Miletus (Von Gerkan et al. 1928: 45, Fig. 55), and the Maison Carrée in Nîmes (Amy and Gros 1979: 55, Pl. 20), shows that there was originally a gap between the bottom of the voussoir and the top of the architrave, which allowed the central block to transfer the load of the upper entablature to the imposts and thus to the columns. The true lintel arch was also occasionally used for architraves, as in the Augustan limestone portico in the Forum at Pompeii (Mau 1902: 53), or, concealed by marble veneer, in the Temple of Apollo Sosianus in Rome (Colini 1940: 24–6).

The application of the lintel arch to columnar orders, where the stability at each impost relies on the equal and opposite thrust developed by the balancing lintel arches combined with the weight of the superstructure, reveals a growing understanding of the device. The first, and most important, step must have been the realisation that the lintel arch could be used even when the abutments were not embedded in heavy masonry, so that the device was not limited in use to openings in walls but could be applied to colonnades. Its use in relieving the load from the architrave is particularly sophisticated; in a way it is the inverse of the balanced cantilevers found in the same position, and used for the same purpose, in some Greek construction (Dinsmoor 1910; Thompson 1960: 359–63). The use of architrave and relieving lintel arches at Rome appears to have been abandoned only after the greater strength of a new material – marble – had been appreciated; the process of innovation involves rejection of outmoded techniques as well as the adoption of new ones.

The earliest surviving concrete lintel arches also belong to the late second or early first centuries BC, and their uses parallel those of masonry arches. They occur most frequently over doors, windows and flat-topped niches, but were also used as architraves between piers or columns, as in the first century BC cryptoporticus of Piazza Tani at Tivoli (Giuliani 1970: 95–107) or the nymphaeum from the so-called Villa of Cicero at Formia (Crema

1959: 124–5, Figs 112–14). Under the empire, their most common use was for square-headed niches and to a lesser degree for openings in walls. Spans were normally limited to 3–3.5m – the same as most stone lintels – with a maximum of 4m. The evidence for concrete lintel arches over wide openings is mainly from Rome itself, and primarily from the palaces and villas which were the testing ground for much of the 'concrete revolution': the Domus Aurea, Domus Augustana, Villa of Sette Bassi, etc. (Crema 1959: 267). By contrast, wooden architraves or low segmental arches were preferred for most openings in the domestic and utilitarian structures of Ostia (Packer 1971: 21–4) and are frequently found at Pompeii; stone lintels were also occasionally employed in otherwise concrete structures, e.g. the Central Baths at Pompeii (Adam 1984: 187), the shops of the Markets of Trajan, and numerous mausolea at Isola Sacra and Ostia. The decision to use a concrete lintel arch must have been governed by several factors – the desire for a homogeneous concrete structure, the need for flexibility, for example in a curved wall, the economics of construction, or the saving in precious materials – but the primary impulse must have always been aesthetic.

The most important feature of these lintel arches for this discussion is the occasional use of stone imposts within an otherwise predominantly concrete construction, the arch itself being faced with bricks or tufa blocks. In the early examples, e.g. the cryptoporticus of the Piazza Tani cited above, it appears to be a remnant of the purely ashlar tradition, the imposts being little more than wedge-shaped or triangular blocks filling the spaces between adjacent lintel arches. By the middle of the first century AD, however, brick lintel arches are found in combination with substantial travertine imposts in several places in the Domus Aurea, most notably in the octagonal room (Fabbrini 1987: 165–79), and similar construction survives from the second century, e.g. at Ostia in the Caseggiato del Larario (Calza 1953: 207, Fig. 53), or in the façade of the Villa of Sette Bassi (Lupu 1937: fig. 38). In all cases the lower edge of the impost projects slightly beyond the vertical face of the opening, making use yet again of the principle of the corbel. There is an obvious parallel here with the stone lintel arches of the Markets of Trajan discussed above, but the same constructional advantages cannot be argued.

This construction reveals, I believe, a great deal about how Roman builders thought about their structures. Most of the surviving examples have considerable spans – 3.5m in the Caseggiato del Larario, nearly 4m in the Domus Aurea and Sette Bassi – which would have tended to fracture at the supports as well as at the centre. The solution seems to have been to turn the concrete arches into masonry arches by providing them with discrete imposts. The discontinuity introduced by the travertine may in fact have promoted failure at the supports on a 'suitable' inclined plane, rather than vertically. Travertine was the normal material to use in both ashlar and concrete construction in places of particular stress (Blake 1947: 44–8; Lugli 1957: 319–20, 354), so it is not surprising to find it here also.

The metal tie-bar

Structural properties

The great advantage of a metal bar is its ability to resist tension. Surviving traces show that the material most commonly used was iron, doubtless in the form of wrought iron

(Tylecote 1962: 241–2), which has a tensile strength as much as 70 times that of concrete. Wrought iron can be made into beams or cantilevers, and was used as such occasionally by Greek architects (Dinsmoor 1922). There were disadvantages. Under load, an iron beam will bend long before it is in any danger of failing. This problem can be countered by increasing the depth of the beam, but the manufacture of large elements in antiquity was by hammer-welding several blooms together, so that the increase in depth required considerably more work. The widespread use of such beams would not, therefore, have been economically viable, although they were certainly employed in conditions where stone was unsuitable, e.g. at the stoke-holes of bath buildings (Tylecote 1962: 237–41).

A fundamentally different way to utilize the tensile strength of iron, however, is the tie-bar, which resists directly the forces tending to thrust a structure apart. Since iron ties support no loads and ideally suffer no deflection, they can be much thinner than iron beams and are therefore easier to make. The main difficulty lies in devising a suitable connection between tie and structure which can transmit tensile forces effectively, or the tie will simply pull away from its anchorage. In Greek and Roman ashlar construction, it is the setting of the iron or bronze clamps in lead within cuttings in the stone which allows the transmission of tension.

The innovation

Although iron was used for beams in Greek architecture, there are no precedents for the use of iron tie-bars across barrel-vaulted spaces, as has recently been proposed for several buildings in Rome. The earliest example (Fig. 8a) is in the upper floor arcades of the Augustan Horrea Agrippiana in Rome (Bauer 1978: 139–43). Cuttings in the upper surface of several travertine blocks (Bauer and Pronti 1978: nos 36–8; 83–4), belonging to the top of the arcade piers and the walls between the chambers opening off the barrel-vaulted passage respectively, are reconstructed as holding iron tie-bars, roughly 6–10cm in cross-section, which spanned the passage at the level of the springing of the vaults. Bauer has also identified similar cuttings on frieze blocks from the portico of the Basilica Aemilia, another Augustan building (1978: 139, n. 19; cf. Amici 1982: Fig. 54). In the Basilica Ulpia (Fig. 8b), Amici has restored tie-bars between the colonnades of the lower aisles, although this time the bars were attached to entablature blocks over both sets of columns and passed through the shallow crown of the barrel-vault covering the aisles (1982: 32–5), thus being concealed from view; she finds some slight evidence also for exposed tie-bars at the level of the architrave cornice in the upper level (ibid.: 42–3) similar to those restored for the Horrea Agrippiana. A related concealed system operated in the palaestrae colonnades of the Baths of Caracalla (Fig. 8c) and the Baths of Diocletian, although there one end of the ties was anchored to the outer wall by means of stone blocks embedded in the concrete (DeLaine 1985: 198–202).

The function of the iron ties ought to be to resist an outward thrust. Contrary to the commonly held belief in the inertness of the Roman vault, recent work on the Pantheon dome (Mark and Hutchinson 1986) has suggested that a concrete vault will exert a thrust on its supports not only while the mortar is wet, but also after it has set. In nearly all the cases we have been discussing, the thrust of the vaults has to be taken on columns and their connecting lintels; the only exception is the Horrea Agrippiana, which is an early example

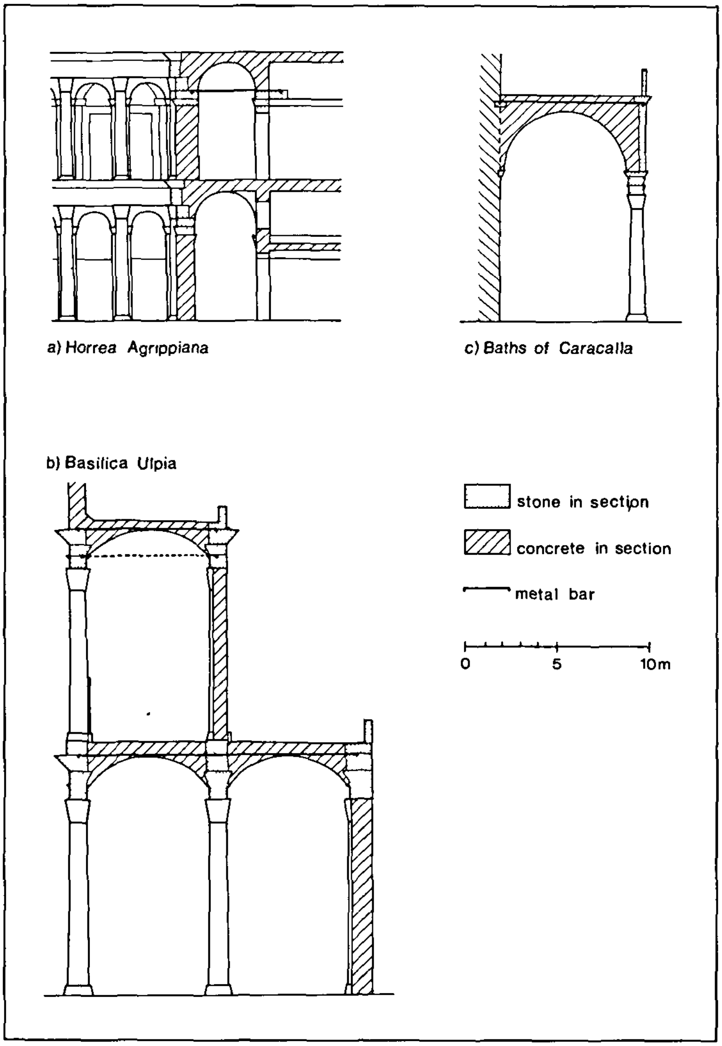

Figure 8 Iron tie construction: (a) Horrea Agrippiana (after Bauer 1978: Fig. 4); (b) Basilica Ulpia (after Amici 1982: Fig. 53); (c) Baths of Caracalla, palaestra.

and perhaps represents an experimental stage. Where the supports are slender and/or widely spaced, the thrust may be sufficient to cause this fragile 'wall' to buckle and ultimately collapse. It is just this tendency to buckle which the tie-bars are designed to counteract by resisting the horizontal component of the force. In both the Basilica Ulpia and the Baths of Caracalla, the vaulting has a lightweight aggregate, another device used to reduce the thrust of the vault.

A different use of iron tie-bars in connection with columnar orders, is found in several buildings in Hadrian's Villa at Tivoli. The material has recently been published and requires only a brief description (Fig. 9). The system is found linking the columns of the 'Sala dei Pilastri Dorici' and the adjacent 'Ninfeo' (Olivier 1983: 940–51), the portico of the 'Teatro Marittimo' (Pl. 6) (Ueblacker 1985: 39–40), the façade and lateral colonnades of the 'Serapeo' (Aurigemma 1954: 328; Olivier 1983: 944), and the internal order and possibly the columnar openings of the 'Stadium' (Hoffmann 1978, 1980: 26). In each case,

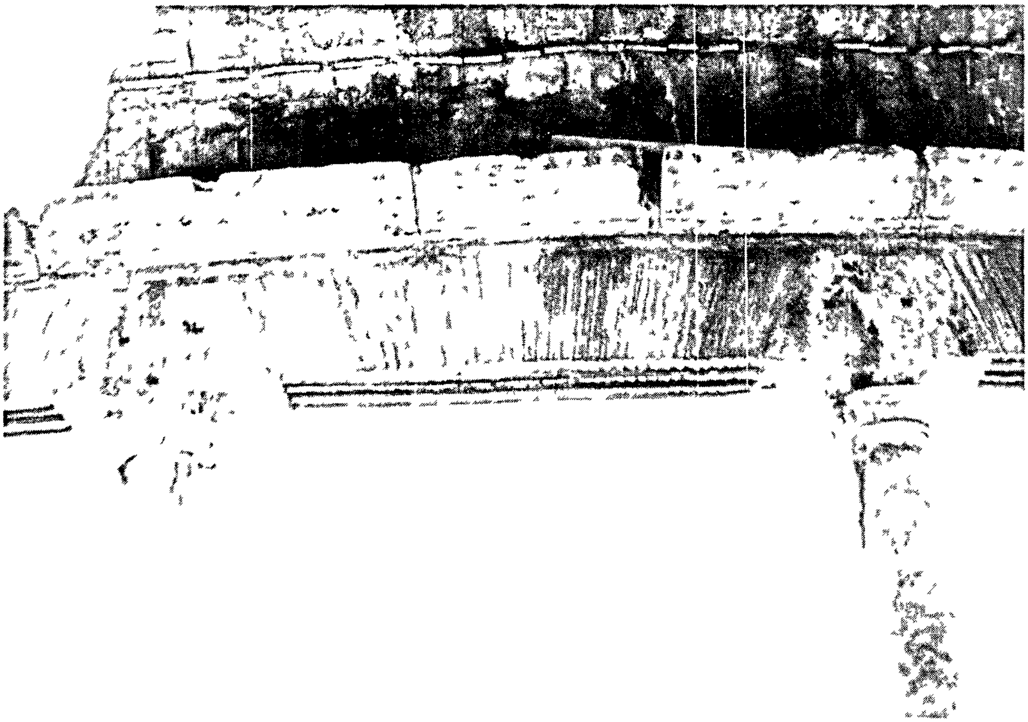

Plate 6 Impost and tie construction, 'Teatro Marittimo', Hadrian's Villa, Tivoli

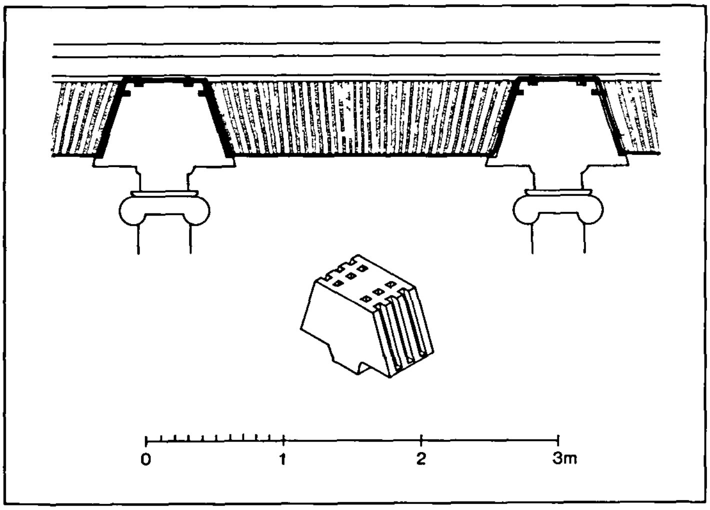

Figure 9 Impost and tie construction, 'Teatro Marittimo', Hadrian's Villa, Tivoli (after Ueblacker 1985)

the columns carry a trapezoidal impost block, the sloping sides of which have two or three grooves cut into them. Iron bars linking adjacent columns were dowelled into these grooves and the ends fixed into the top of the blocks with lead, the resultant armature supporting brick-faced concrete lintel arches. The neck at the bottom of the impost blocks allowed a marble soffit block also to rest on the columns below the lintel arch, and the faces of the architrave were also sheathed in marble, a system similar to that employed in the Temple of Apollo Sosianus (see above).

The origins of this type of construction are not difficult to seek. We have already noted the use of concrete lintel arches with travertine imposts for the wide openings in the Domus Aurea and other buildings, and of lintel arches for the architraves of columnar orders in ashlar construction. The iron bars could be imagined as acting in three ways: as an aid to construction by providing a permanent formwork for the lintel arches; as beams preventing the loads on the architraves being transferred to the thin soffit slabs below; or as a tie linking all the columns together, so that the columnar 'wall' would act as a single unit. Thus braced, and either tied to a solid support at the ends or linked into a closed circuit as in the portico of the 'Teatro Marittimo', the colonnades could offer a greater resistance to any outward thrust generated by the vaulting that they supported.

The fixing of the bars to the imposts would only be necessary if the system were expected to be subject to tension. A comparison with the scheme suggested for the colonnaded porticoes at Conimbriga, which also appear to have used metal bars with stone impost blocks to support lintel arches, is illuminating (Olivier 1983: 954–9). There the bars fit into slots on the underside of the imposts and there are no dowels; other blocks exist with cuttings for the ends of timber beams, or with no cuttings at all. Olivier believes that a single bar ran the whole length of the central colonnade in each arm of the U-shaped double gallery, and that these bars were joined at the corners to form a single armature – a total length of 65m which would have to be put in place over the column capitals before the impost blocks! It is much more likely that the individual bars spanned from one block to another and acted as simple beams to support the lintel arches, just as wooden beams formed the basis of the architraves for the outer colonnades. The lack of any obvious tension connections contrasts strongly with the otherwise similar system at Hadrian's Villa, and encourages us to treat the latter as a tension system fulfilling a similar function to the ties across vaulted colonnades.

If we think of these two systems primarily as ways to ensure the stability of colonnades against lateral thrust, it is possible to recognize a further development of the same structural concept in the iron or timber ties which were quite widely used in Byzantine and medieval construction. In a recent evaluation of the use of reinforcement in early buildings, Wilcox came to the conclusion that tie-rods between arches of a colonnade and between a colonnade and its outer wall evolved as a protection against earthquakes in the eastern Mediterranean (1981: 72). Nevertheless, his earliest example of metal rather than wooden ties is in the early fifth-century AD church of Santa Sabina in Rome, although he has to suggest that the inspiration came from the east. Is it not more likely that this was just a further development of what was certainly by the time of Diocletian a well-established, if perhaps not very common, Roman construction technique?

Conclusions

The corbel, lintel arch and iron tie all belong in the same context of experimentation which took its Roman inspiration primarily from ashlar construction. In all three cases the innovation was based on a pre-existing principle, but some at least of the specific uses to which it was put were new. With the corbel the advantages of the innovation were mainly structural, but the adaptation of the device for supporting balconies created a new aesthetic effect. The lintel arch, on the other hand, was always a structural device, developed to perpetuate a traditional trabeated aesthetic in a situation where the local materials were structurally inadequate for the desired scale of the building. The iron tie-bars were used in mixed constructions, where columns or masonry piers supported a concrete vault, and were therefore a response to the new concrete architecture; nevertheless, the tension connections were created by fixing the bars into stone anchorages with lead – a device clearly borrowed from the use of clamps and dowels in ashlar masonry.

All three devices were also exploited to enhance the potential of concrete construction by capitalising on the structural or constructional advantages of other materials, whether stone or iron, or both. The development was progressive, one innovation seeming to inspire another. The anchor blocks in the Baths of Caracalla and Diocletian and the imposts from Hadrian's Villa, can be thought of as derivatives of, for example, the travertine corbels used in the cross-vaults at Hadrian's Villa and lintel arch imposts of the Domus Aurea respectively. The addition of the metal ties, however, transformed the system completely.

The corbel, lintel arch and tie were only ever peripheral to the mainstream of the Roman architectural revolution, even if they did make a modest contribution to it. As I have tried to show in this paper, their importance lies not as elements in their own right but rather as indicators of an active process of architectural innovation and its controlling factors, a process not confined, despite the current myth, entirely to vaulted concrete.

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St John's College
Oxford

Note

Photographs and drawings are by the author.

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Abstract

DeLaine, Janet

Structural experimentation: the lintel arch, corbel and tie in western Roman architecture

The paper investigates the origins and development of the lintel arch, corbel and metal tie in Roman architecture, concentrating on the structural principles involved and the structural and constructional advantages of each, as a means of investigating the processes of Roman architectural innovation outside the normal parameters of the 'concrete revolution'. All three devices are seen to derive ultimately from the tradition of Roman ashlar construction, but were subsequently developed by exploiting the specific properties of both stone and metal within an otherwise concrete architecture. While the corbel was used as a support for concrete vaulted balconies creating a new aesthetic motif, the lintel arch and tie-bar were structural devices developed to perpetuate a traditional trabeated aesthetic in a situation where the local materials were structurally inadequate, or the combination of columnar order and concrete vault threatened the stability of the structure.