DETAILING OF JOINTS SUBJECTED TO CONCENTRATED FORCES AND JOINTS IN SHELLS MADE OF REINFORCED CONCRETE

by

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Abstract

Detailing of joints is crucial to simulate the desired behaviour of a structure. Unlike other materials like timber or steel, reinforced concrete joint itself is normally not designed specifically and hence design codes, handbooks and textbooks on design give little information on joint detailing. However, detailing manuals give typical examples, but theoretical concepts behind detailing are not emphasised. This results in inaccessibility to most of the valuable information on detailing which remain in research papers. Further, detailing techniques have changed considerably in the light of recent research and such changes should be noted by designers. Thus there is a strong need to provide current detailing information for use by practising engineers.

This is a continuation of a study on detailing of reinforced concrete and deals with more specialised topics covering detailing of joints subjected to concentrated forces and joints in shells. This part of the study covers continuous nibs, halving joints, hinges, corbels and various joints in shells.

The paper highlights the theoretical concepts on detailing related to above topics, brings to focus current trends in detailing, and illustrates by examples how other situations can be treated.

1.0 Introduction

Theoretical principles and information on detailing of reinforced concrete are still not freely available in textbooks, handbooks, codes of practice and detailing manuals. However, rapid changes in understanding are taking place in detailing techniques due to recent research findings. Further, the most difficult situations for detailing are the various joints in reinforced concrete. Thus a strong need exists to disseminate more information on detailing of reinforced concrete joints.

Guidance on detailing techniques is now engaging the attention of research workers. Some studies have already covered detailing of simple reinforced concrete elements(1) and some widely used joint types(2). This study deals with those of joints subjected to concentrated forces (such as continuous nibs, halving joints, hinges and corbels) and various widely used joints in shell structures formed by intersection of planar, spherical, cylindrical and conical segments.

This paper is based on a review carried out on detailing of those joint types and it also illustrates the extension of theoretical principles and detailing methodology evolved here, by treatment of some examples of other joints.

2.0 Continous nib

The common applications of a continous nib (Figure 1) are : (a) as supports to precast beams, slabs or staircase; and (b) as supports to facing brickwork where concrete structure is completely concealed. It can occur in reinforced concrete slabs, beams or walls, but it is very common with beams.

There are two methods for designing continous nibs. In one method(3,4) nib is treated as a short cantilever slab, while in the other(5,4) truss action is utilised for load transfer. Both methods are found(4) to give similar steel areas and the former method is more appropriate for nibs less than 300 mm deep. Steel areas in the nib can be calculated by either method from the formulae given by Reynolds & Steedman(4). Other noteworthy considerations are :- (i) The maximum bending moment of the nib should be taken as the distance from its line of action (at outer edge of the bearing pad, at beginning of chamfer or at outer edge of nib) to the nearest vertical legs of the links in the beam or to the nearest vertical reinforcement in the element; (ii) Links of the main beam or vertical reinforcement of the main element should be able to transfer the load from the nib to the compression zone of the main beam or element in addition to any other forces which they resist; (iii) Tension reinforcement in the nib should extend as near to the front face of the nib as possible without violating cover requirements and should be anchored there, either by welding to a transverse bar of same size or by bending through 180° to form loops in the horizontal or vertical plane. Vertical loops should be of bar size not greater than 12 mm; and (iv) In the case of vertical loops, bend should not begin before the edge of bearing of the load. If it is not possible U bars should be used.

Vertical loops or U bars are not considered efficient and hence are suited for low load carrying situations (a,d,e and j, Figure 1). The most efficient arrangement of vertical links with X-bends (i, Figure 1) is used for high load carrying situations, but difficulties in incorporating the steel occur with shallow nibs if the vertical bends are to meet the minimum radii requirements

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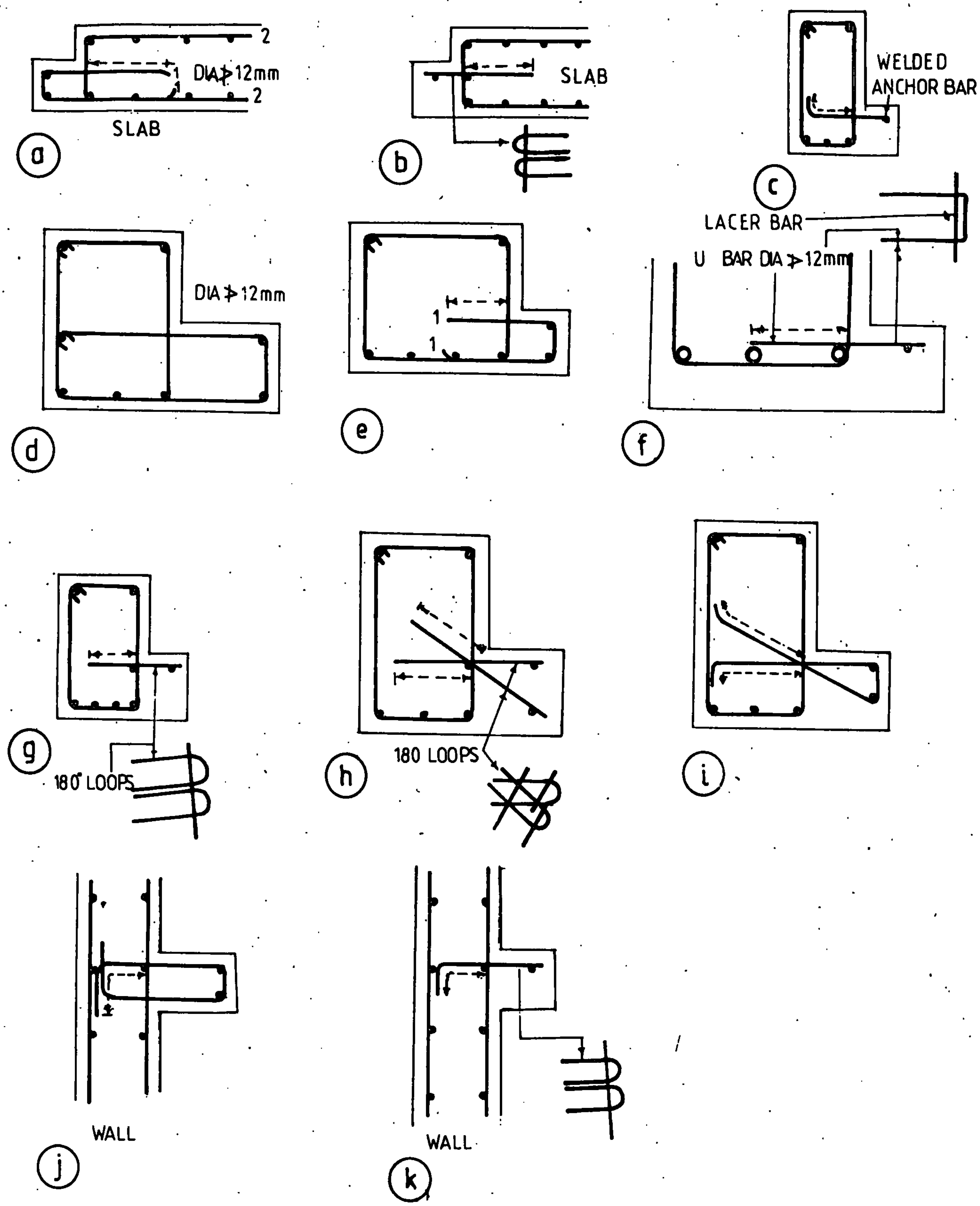


←- - - -→ anchorage length (measured along reinforcement)

Figure 1 - Continuous nibs

and hence not suited for shallow nibs. Arrangement of horizontal loops (b,f,g and j, Figure 1) is reasonably efficient and it is simple to anchor the reinforcement at the outer face of the nib. However, tests have shown that capacity of the nib does not increase with an increase in the bar diameter, due to splitting along the line of steel. Arrangement of horizontal and inclined loops (h, Figure 1) is also considered efficient, while still being fairly simple to fix and hence recommended for high load carrying situations even with shallow nibs. In all these methods nib steel should be extended to the main element to provide adequate anchorage bond length as shown by dotted arrows (a,c,e,f,h,i,j and k, Figure 1).

For nibs in slabs, arrangements a (low load) and b (high load) of Figure 1 can be used. For nibs in beams, arrangements c (low load), d,e,f,g,h(high load with shallow or deep nib), i(high load with deep nib) (see Figure 1) can be used. For nibs in walls, arrangements j(low load) and k(high load) of Figure 1 can be used.

3.0 Halving joint

Applications of this joint are found in precast beams, slabs or staircases where supporting arrangement is such that the depth of element is too much to be supported from soffit of that element and hence should be supported from a surface at approximately half the depth (see Figure 2).

Free body diagram of a halving joint is shown in a of Figure 2. Area of inclined links, area of horizontal steel to resist additional horizontal forces and anchorage length of bottom main steel reinforcement beyond the inclined links can be calculated(4) from CP110(3) recommendations. The design assumes a 45° crack at failure (a, Figure 2) and that the inclined links (a and e, Figure 2) which provide the tensile force F_t can reach their design strength. These assumptions are justified provided that reinforcement is detailed as in various arrangements of Figure 2, and that maximum vertical ultimate load F_v is limited by concrete shear strength as in CP110(3). The inclined links must intersect the line of action of F_v (e to h, Figure 2). If this cannot be ensured (for instance if the inclined links may get displaced) or if horizontal forces may act, horizontal links must also be provided (bar 4 of e or g, Figure 2). Half the force in the inclined links is transferred(6) to the main reinforcement by bond and the other half by friction, which means that the links should be tightly wired to the main steel. The most efficient way of anchoring the horizontal reinforcement above force F_v (e, Figure 2) is in the horizontal plane. Some reinforcement should always be present here, even if no horizontal forces are acting, to guard against the inclined links being misplaced (bar 4 of e or g, figure 2). Force F_t can also be provided by a combination of horizontal and vertical links or bars (b, c or d, Figure 2).

In slabs, inclined links are diffidult to provide due to lack of space, and since they are lightly loaded the detailing should be as for continous nibs (b or c, figure 2) without using inclined links. Joints carrying low to medium loads should be detailed in the sequence d (low loads), e, f and g (medium loads). Joints subjected to high loads require passage of many 45° bars across the line of action of force F_v and details suited are h-and i of Figure 2. Detail i is stronger as it has three inclined bars as opposed to two across the line of action of the external reaction (h, and i, Figure 2).

4.0 Hinge

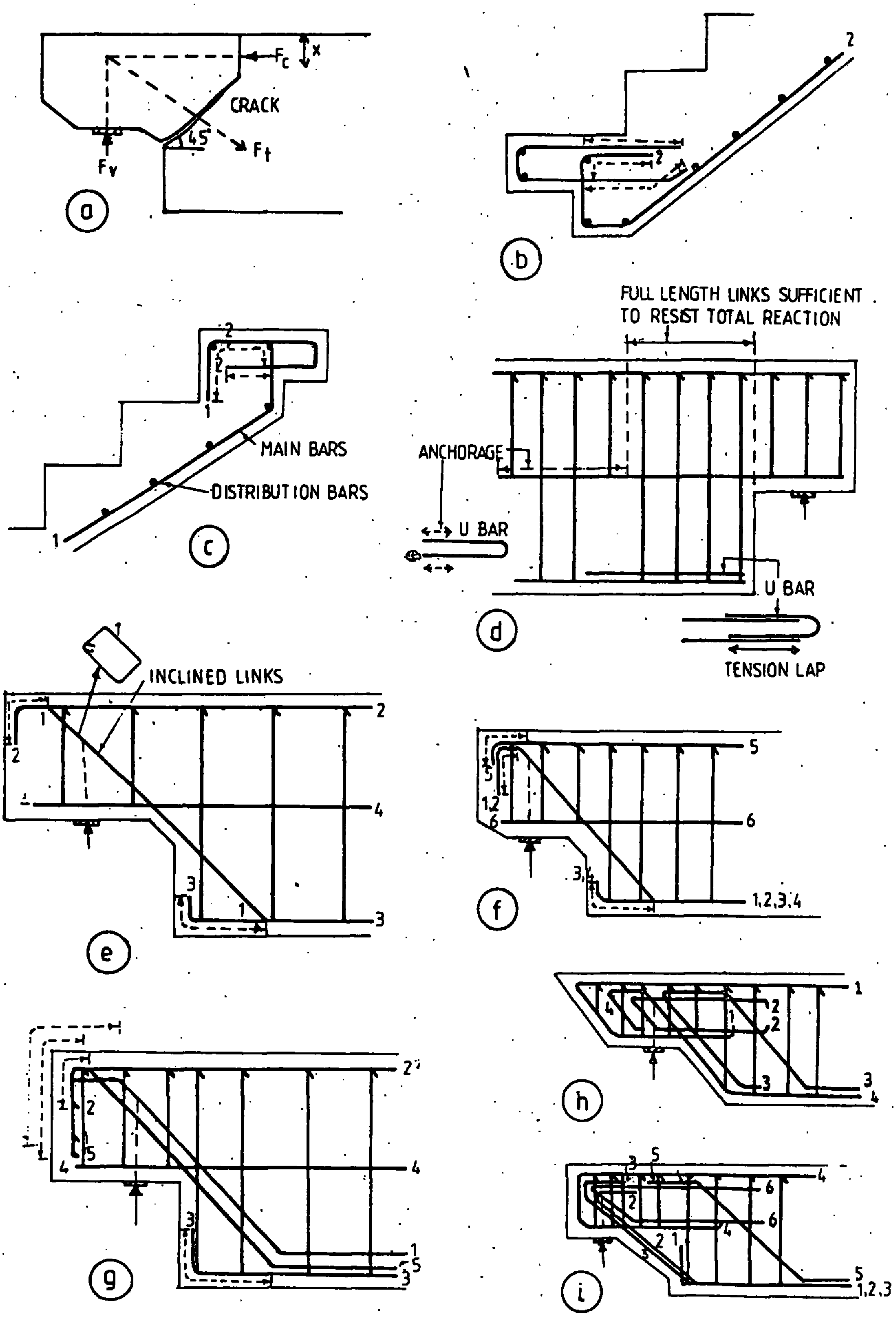
The main applications are support hinges of long span beams, hinges of two or three-pinned portal frames or arches and wall hinges.

In the construction of frames, arches or other monolithic structures, hinges are necessary(7 to 10) at points where it is assumed that there is no bending moment either to make the structural behaviour independent of foundation settlements or to prevent transfer of bending moment to some parts of the structure. Hinges are elements which can transmit a thrust (or tension) and a shear force, but permit rotation without restraint. In buildings, hinges are often placed above the DPC to prevent passage of moisture into the building and to permit easier inspection with minimum amount of disturbance to the finishes.

In large structures, fitting metal hinges (a,b,c,d,f and r, Figure 3) would be very expensive and hence the need to form hinges using ordinary reinforcing bars. This is possible due to the fact that in most reinforced concrete structures, actual rotation required is very small. In a concrete hinge the member is nearly severed and a resilient filler is inserted in the gaps (j,k and l, Figure 3).

Concrete at the centre of the joint should be sufficient to transfer the axial thrust, shear force and provide cover to steel rods, if any. Compressive stress of concrete under ultimate loads should not exceed 0.4 f_{cu} but higher strengths up to 0.8cu can be used(3) provided concrete is confined by additional binding reinforcement to prevent splitting or spalling of concrete. When throat is of concrete only (o, Figure 3) compressive and shear stresses for plain concrete(3) can be used, but it is better to obtain those, and A and T values (in relation to D) experimentally as enhancement of strength by concrete confinement cannot be easily ascertained. In heavily loaded hinges, sufficient amount of confinement reinforcement (l to q, Figure 3), usually as closed links or spirals, is necessary to increase the strain and strength capacity of the concrete in the hinge.

Two gaps of 20 mm thick on either side of the hinge is necessary to reduce bending moment capacity, allow movement and reduce throat concrete strains for a given movement. These gaps are filled with a resilient filler to allow repeated movements without exposure of the concrete throat to the atmosphere and to allow easier inspection at regular intervals.



→---→ anchorage length (measured along the reinforcement)
←——→ lap length

Figure 2 - Halving joint

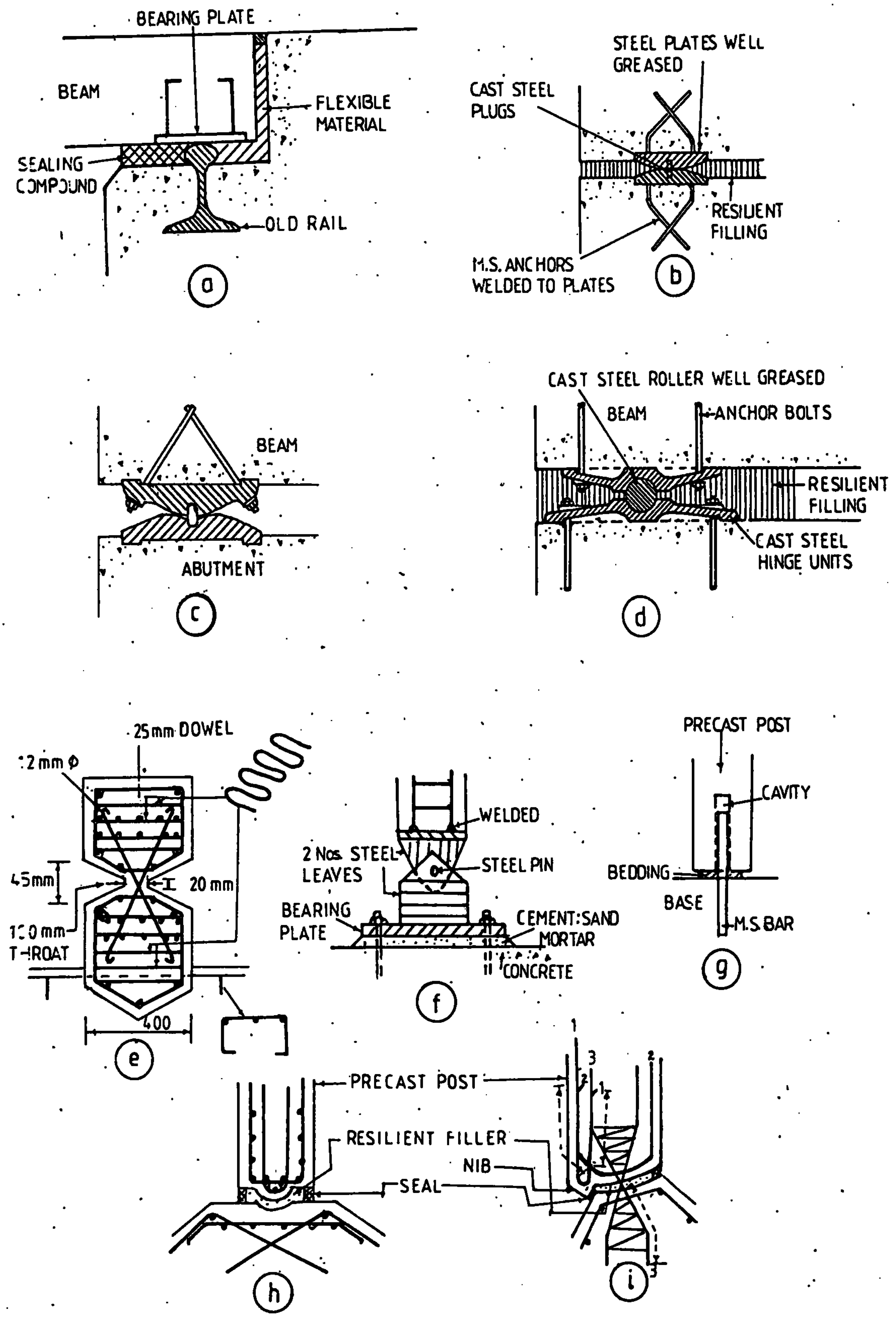


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Figure 3 - Hinges (to be continued)

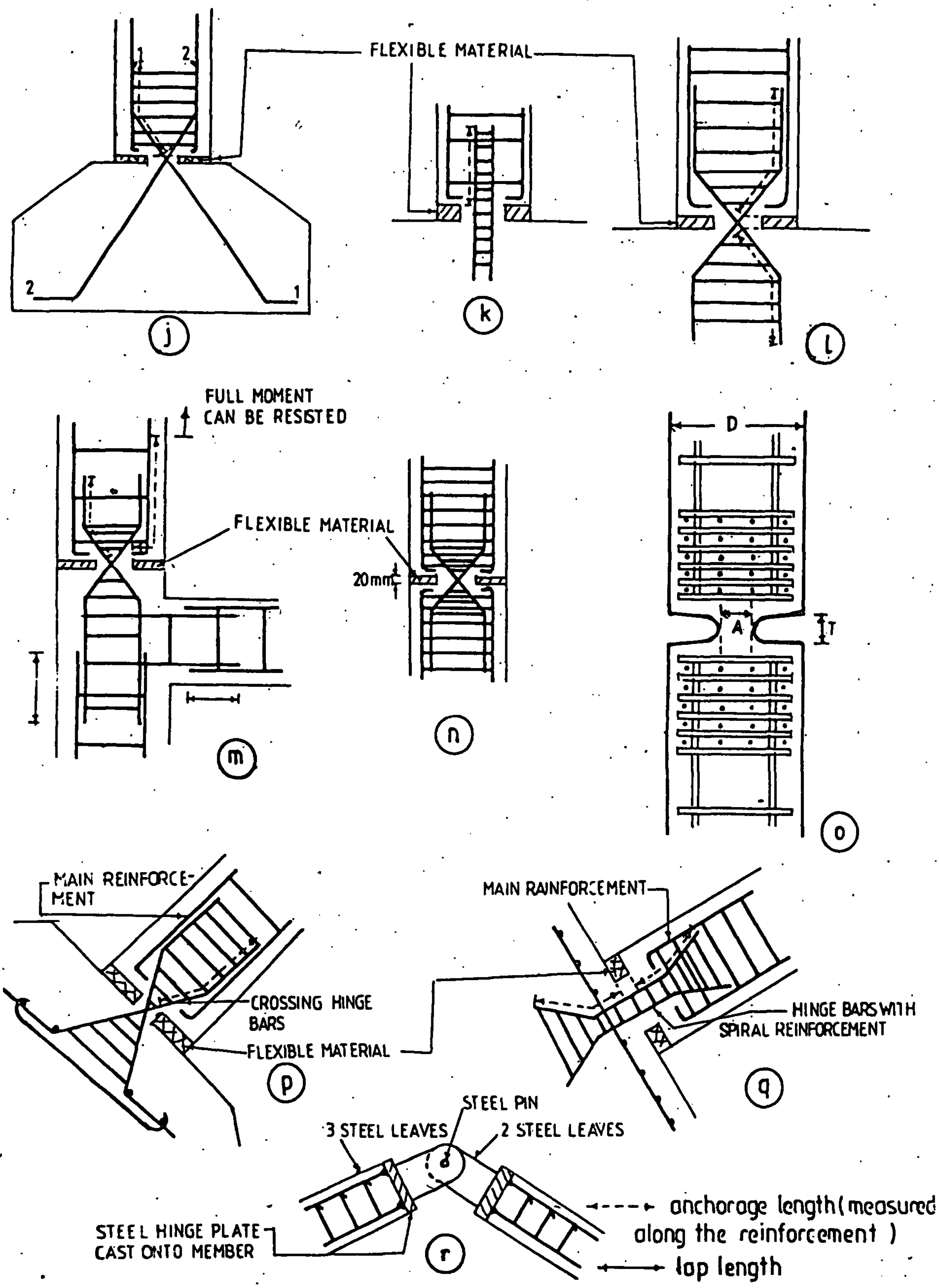
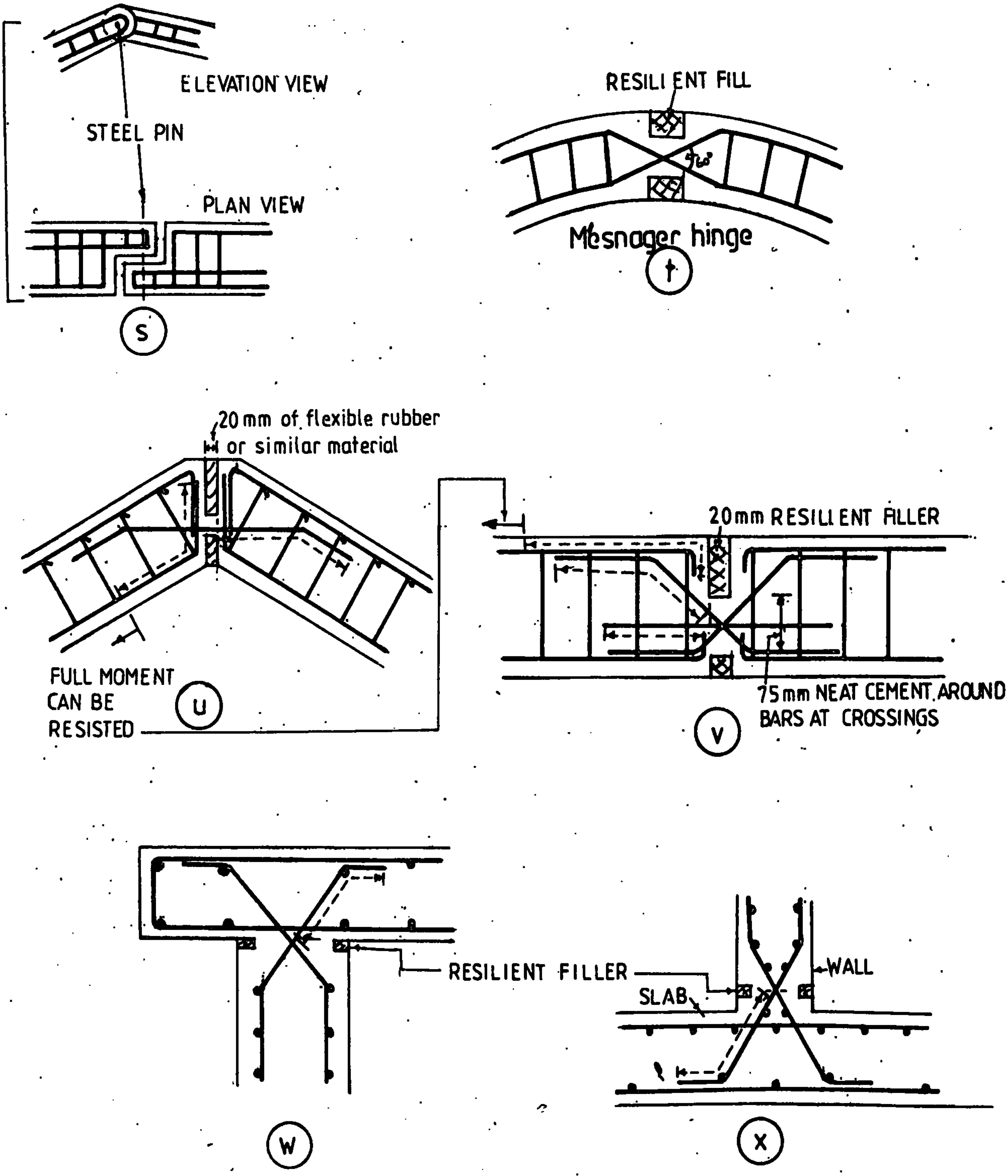


Figure 3 - Hinges (first continuation)



←- - -→ anchorage length (measured along the reinforcement)

Figure 3 - Hinges (last continuation)

Steel area at the concrete throat will depend on forces resisted by steel such as shear or direct tension. Steel reinforcement through the throat can be approximately parallel (k and q, Figure 3) or the bars can cross each other in a x-shape (e,i,l,m and p, Figure 3). In either case, concrete near the throat is confined by additional binding reinforcement, except for lightly loaded hinges (j,w, and t, Figure 3).

Support hinges of long span beams can be detailed (see Figure 3) as a (less movement), b, c or d (more movement) using metal hinges or as e for concrete hinges. For short span beams, hinges are not essential and a dowel bar at the support is sufficient. Column hinges can be detailed as in f (metal hinge) or as in g (lightly loaded) to o(heavily loaded). Hinges of arch abutments can be detailed as in f (metal hinge), p (lightly loaded) or q (heavily loaded). Crown hinges can be detailed as in r (metal hinge), s(small loads), t(medium loads and same movement in either direction), u(medium loads and movement causing compression on bottom fibre is greater) or v(higher loads and movement as for u). Wall hinges can be detailed as in w (small loads) and x(high loads). Bars at the hinge should be extended to provide anchorage bond length of the bar beyond the end of the concrete throat (l,q,u, and w, Figure 3), as shown by the dotted arrows.

5.0 Corbel

Point loads originating from gantry girders or precast concrete beams are often carried by projections, called corbels, very near the face of the supporting columns or walls. A corbel(3) is a short cantilever beam in which the point load acts such that the distance between the line of action of the load and the supporting column or wall is less than 0.6 times the effective depth of the main tension reinforcement. In ACI(11,12) recommendations the above factor 0.6 is increased to 1.0. In a corbel, effective depth and height changes along its length as opposed to a nib.

Corbel should be designed as a simple strut-and-tie system (a, Figure 4) for loads appropriate to the ultimate limit state. For the corbel to form this system at failure, occurrence of shear failure should be eliminated by determining the effective depth based on shear considerations. The strut-and-tie system gives rise to tension cracks which are nearly vertical (a, Figure 4) and thus the design emphasis is on placing horizontal reinforcement to resist this crack formation. Design process widely used should be followed(4,3,11) in proportioning and designing of corbels. As the bending moment changes rapidly, local bond should be checked to ensure sufficient bar perimeter is provided at all sections to withstand the expected changes of force in the bars per unit length due to change in the applied bending moments.

Because corbels are small in size, details of bond, anchorage and bearing are very important. Tension bars may be fully stressed(12, 14) up to the outside end. They must be anchored at the front face of the corbel by (i) welding tension bars to a cross bar of size greater than or equal to a tension bar (d, Figure 4) with each weld capable of developing yield strength of that tension bar; (ii) anchoring tension bars mechanically by welding to a steel plate (f, Figure 4) or a stiff steel angle (e, Figure 4) exposed on the edge of the corbel; (iii) bending a tension bar in a horizontal loop back into the support (c, Figure 4); or (iv) bending the tension bar into the compression zone and continuing till it reaches the support (b, Figure 4). The bearing area of the load on the corbel should not extend beyond a distance equal to the diameter of a main bar inside (b,c,d,e and f, Figure 4) of (A) the interior face of the cross bar; (B) interior face of the mechanical anchorage; (C) the straight portion of the looped tension bars; or (D) the bend of a tension bar continued into the support member through the compression zone.

Column corbels carrying vertical loads should be detailed as in b (low loads), c and d (high loads), while those carrying both vertical and horizontal loads should be detailed as in e (low loads) and f (high loads). Wall corbels do not require horizontal links and should be detailed as in g or h. Tension anchorage lengths, compression anchorage lengths and lap lengths should be provided as shown in d and h of Figure 4.

6.0 Joints in shells

A joint in a shell structure is normally formed when several shells meet at a ring beam, two shells meet along a straight line, edge of a shell frames into a straight edge beam, or edge of a shell frames into an end diaphragm. Detailing of joints in shells is simpler since ring beam, intermediate beam, edge beam or end diaphragm at the joint is proportioned independent of shell thickness so that adequate space can be created for terminating the reinforcement entering the joint from the shell or shells.

The main considerations to be noted in detailing shell joints are:- (i) reinforcement from a shell entering the joint should be carried through a distance of anchorage length beyond the point where it meets the reinforcement cage of ring beam, straight beam, edge beam or end diaphragm; (ii) in shell joints where no bending is induced, reinforcement should be kept along the middle surface of the shell (a and b, Figure 5); (iii) when shell in the vicinity of the joint is subjected to bending additional reinforcement should be provided at the joint (c and d, Figure 5); (iv) where the beam at the joint is spacious, shell reinforcement should be anchored within it or passed through after bending (e and f, Figure 5); (v) where the beam at the joint is small, stirrups with extended arms should be used as starter bars for the shell reinforcement (a and b, Figure 5); (vi) direct shell to shell joints, in elevation, are rare (g, and h, Figure 5) due to the need to resist the resultant force at the joint by a beam. However, in very lightly stressed shells such joints can be used, and in such situations reinforcement should be detailed (g and h, Figure 5) to ensure that neither concrete pop outs nor reinforcement pull outs will take place under load; and (vii) direct shell to shell joints, in plan, are common in silos. In lightly loaded joints, detailing should only ensure that reinforcement from one shell enters the other shell and travels a distance of an anchorage length beyond the point where it meets the

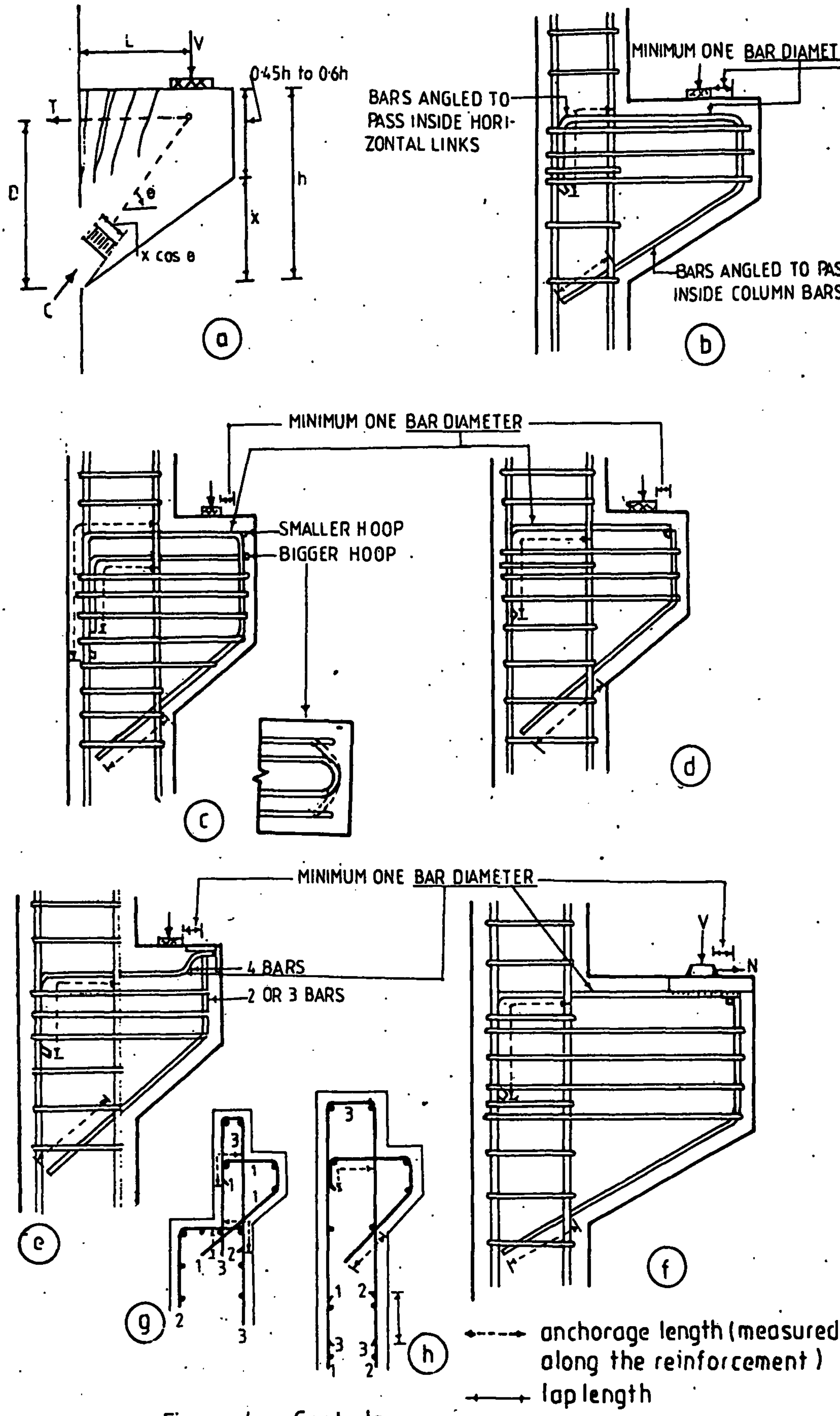
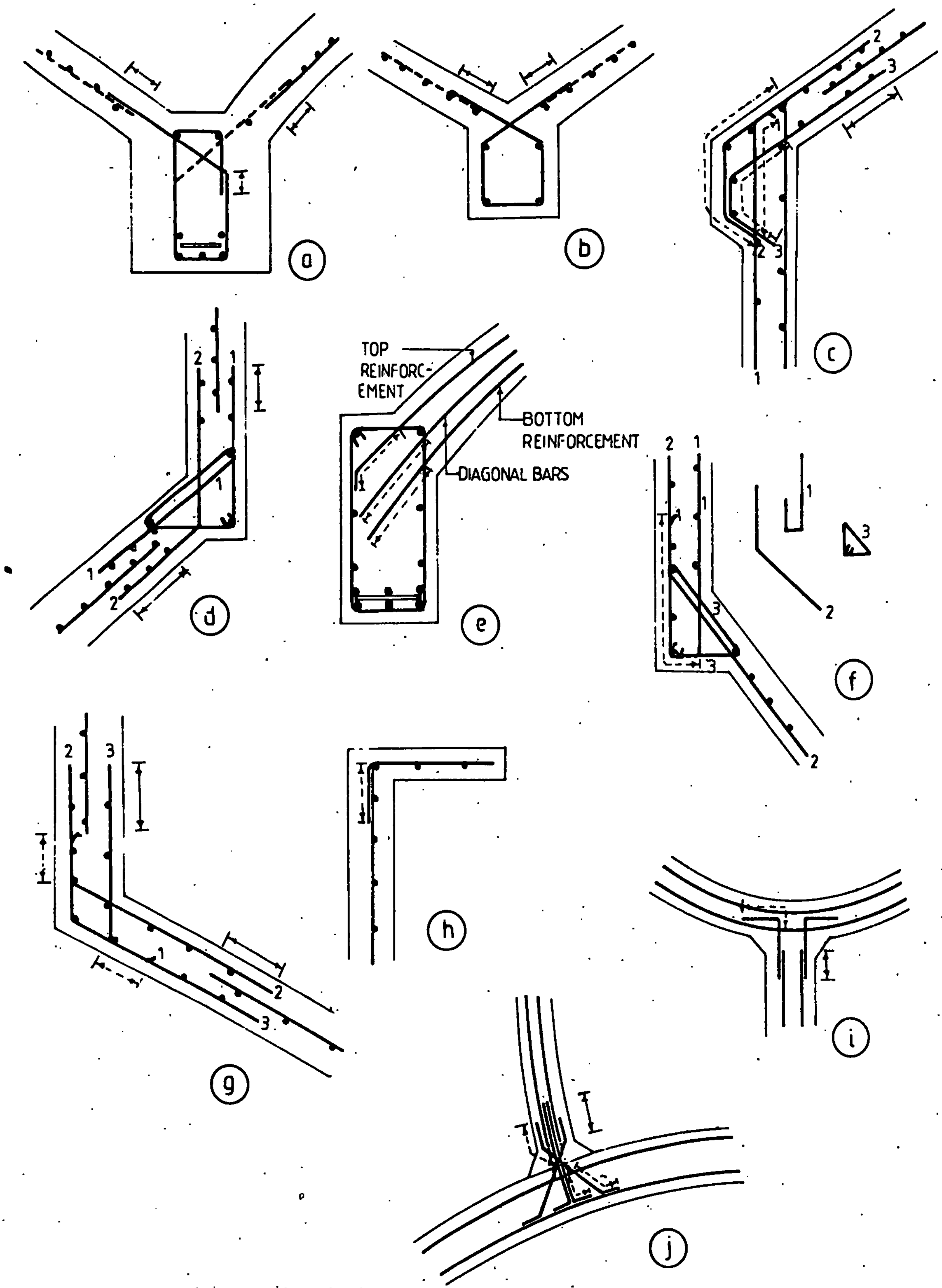


Figure 4 - Corbels



←- - - -→ anchorage length (measured along the reinforcement)
←——→ lap length

Figure 5 - Some noteworthy considerations in shell joints

reinforcement cage of the other shell (i, Figure 5). In rigid joints, detailing should ensure continuation of reinforcement of one shell into the other and provide reinforcement to enlarge and stiffen the joint (j, Figure 5).

Typical joints(8,10,16 to 21) shown illustrate spherical to cylindrical (a and b, Figure 6) spherical to conical (c and d, Figure 6), spherical to edge ring beam (e and f of Figure 6, e of Figure 5), cylindrical to conical (g, h and i, Figure 6), cylindrical to flat bottom (as for wall to slab joints(2), cylindrical to spherical (j and k, Figure 6), cylindrical to cylindrical in elevation (a and b of Figure 5, a of Figure 7), cylindrical to cylindrical in plan (b and c, Figure 7), cylindrical to edge beam (e and f of Figure 6, e of Figure 5), conical to edge beam (d, Figure 7), and conical to cylindrical to spherical (e and f, Figure 7).

When a ring beam at a joint is subjected to asymmetric loads such as wind loads which cause bending moments in it, internal transverse tension is developed(1). This should be resisted by providing stirrups at the required spacing.

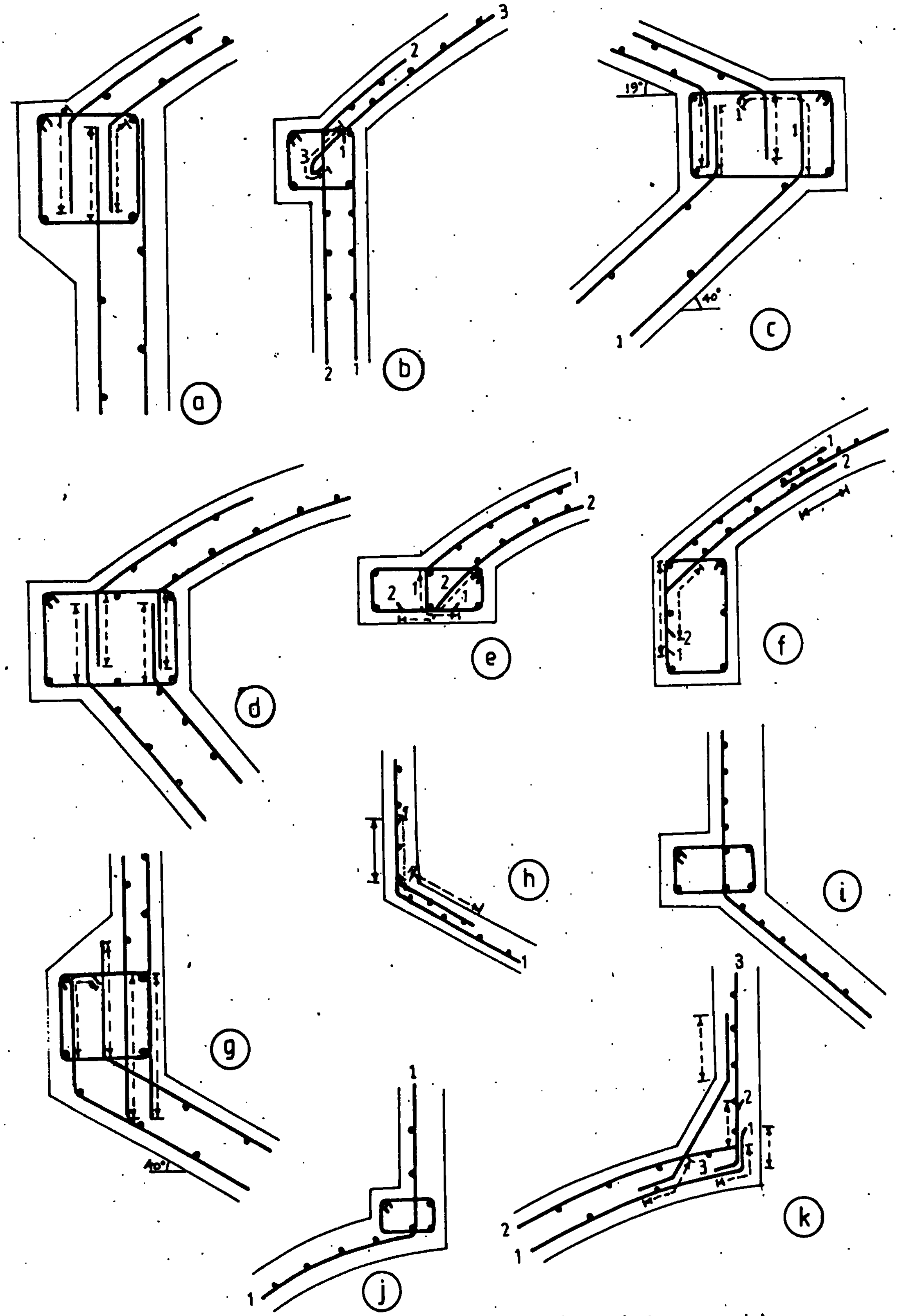
7.0 Illustrations on use of above detailing principles in non-standard joints

Example 1 is a shell-edge beam joint where shell consists of an inverted hyperbolic paraboloid. The edge beam contains a continous nib to support lightweight glazing strips. The intended shape of the joint is shown in a1 of Figure 8, while a2 and a3 depict the reinforcement details of the edge beam with nib and the shell respectively. The detail recommended is shown in a6 of Figure 8, while some alternative details considered are shown in a4 and a5. In arriving at the recommended detail, the following points observed at various decision making stages are noteworthy:- (i) The details are drawn to a scale big enough to represent each reinforcement by two lines; (ii) The reinforcement details of the main components (a2 and a3, Figure 8) meeting at the joint, namely edge beam with nib and the shell, are drawn separately; (iii) a4 is the simplest detail arising out of combination of details a2 and a3. However, as the edge beam is small and hence congestion of reinforcement should be avoided, detail a5 is considered as an alternative; (iv) Detail a5 weakens the nib and amount of weakening will depend on the slope of the shell which varies in a hyperbolic paraboloid. To overcome this shortcoming, detail a6 is recommended where neither the nib is weakened nor cause reinforcement congestion; and (v) Anchorage lengths and lap lengths provided should be adequate and are shown in Figure 8 by dotted arrows and continous arrows respectively.

Example 2 is a joint where a conical shell, spherical shell, ring beam and a battered square column meet together. The intended shape of the joint is shown in b1 of Figure 9, while the recommended joint detail is shown in b4. Intermediate stages of the detailing process is shown in b2 and b3. In arriving at the recommended detail, the following points observed at various decision making stages are noteworthy:- (i) As for (i) of example 1; (ii) The designed reinforcement of various elements framing into the joint are drawn at the intended positions (b2, Figure 9); (iii) Ring beam is enlarged slightly (if necessary) to allow for various reinforcing bars to enter the joint without undue interference (b3, Figure 4); (iv) The bars entering the joint from various elements are suitable bent, if necessary, and continued further to provide adequate anchorage length. In bending the bars, 75mm gaps among bars should be left(1) for insertion of a poker vibrator during concrete placement; (v) Actual ring beam shape is decided by allowing required cover around the reinforcement eage; (vi) To prevent a sharp intersection between conical and spherical shells which may lead to stress concentrations and cracking, bars 1 and 2 (b4, Figure 9) are placed in position and adequate cover provided on top of those bars; and (vii) Anchorage lengths provided should be adequate and are shown in Figure 9 by dotted arrows.

8.0 Closure

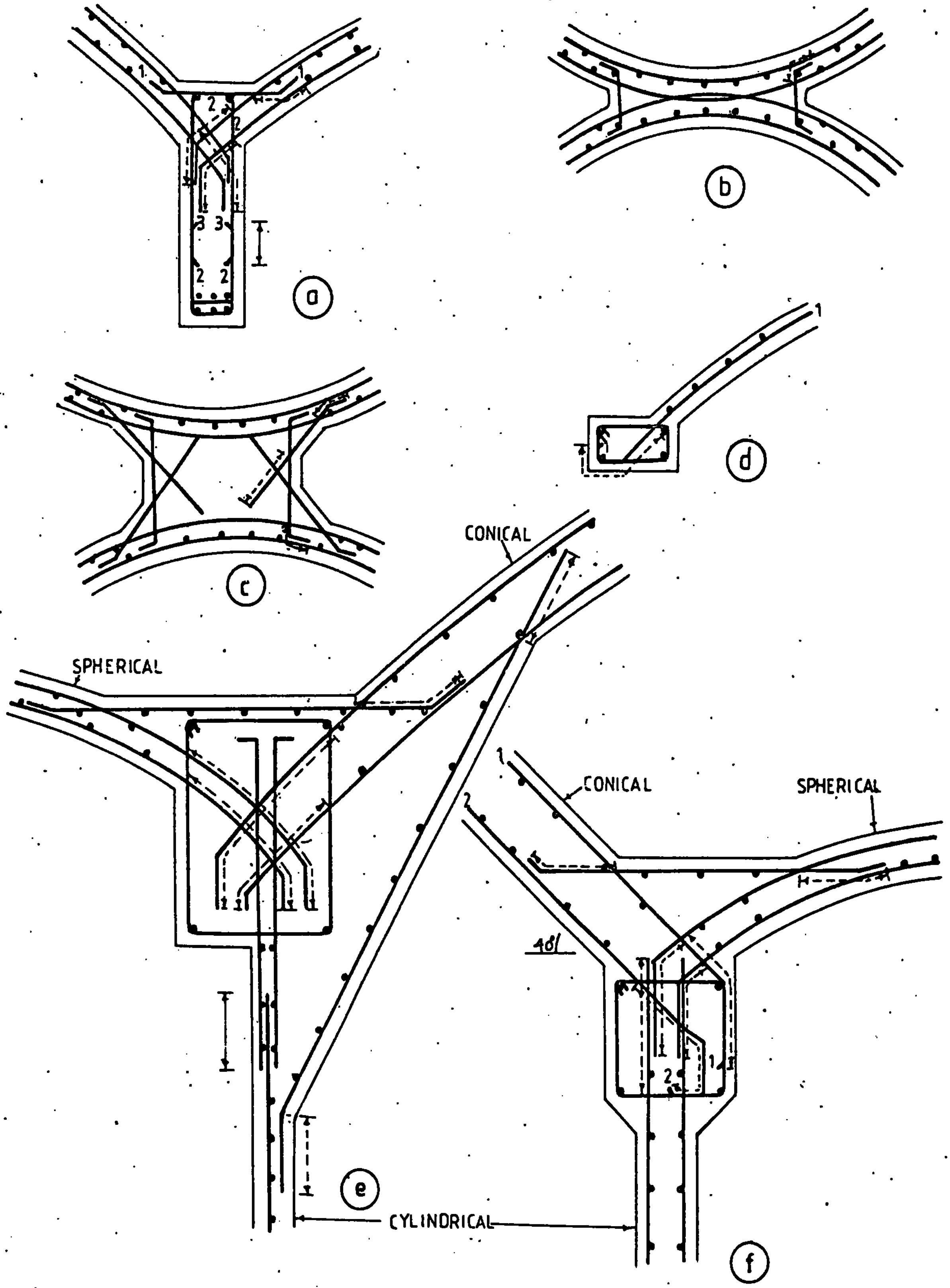
This study (a) highlighted the theoretical concepts behind detailing of joints subjected to concentrated forces and also shell joints; (b) brought to focus current methods of detailing such joints; and (c) gave examples to demonstrate how non-standard joints, not covered specifically in the study, can be detailed using the above concepts.



⇠ - - - - ⇢ anchorage length (measured along the reinforcement)

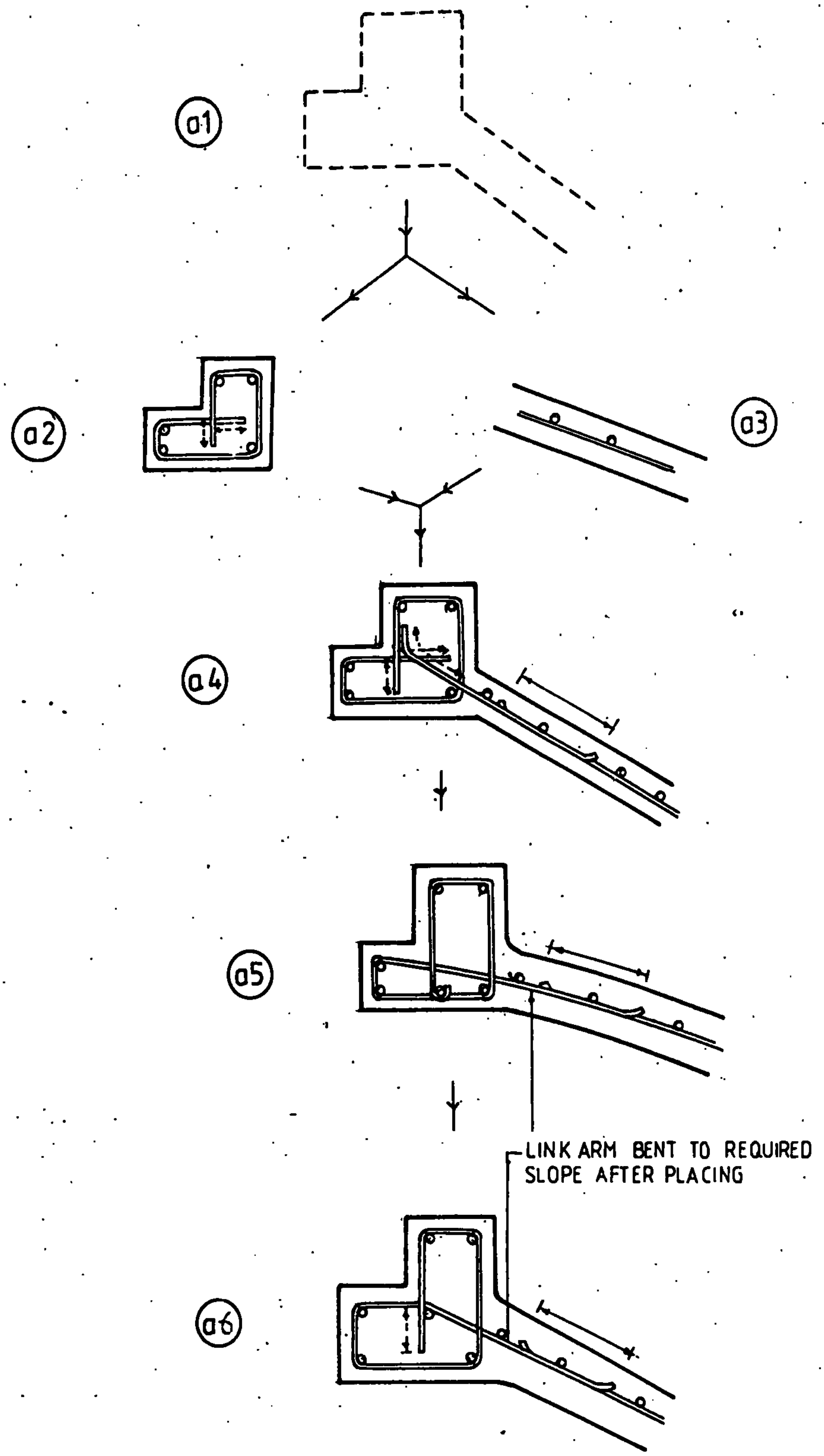
⟵——⟶ lap length

Figure 6 - Typical shell joints



anchorage length (measured along the reinforcement)
lap length

Figure 7 - Further shell joints



◄- - - -► anchorage length (measured along the reinforcement)
◄———► lap length

Figure 8 - Various stages of detailing in example 1

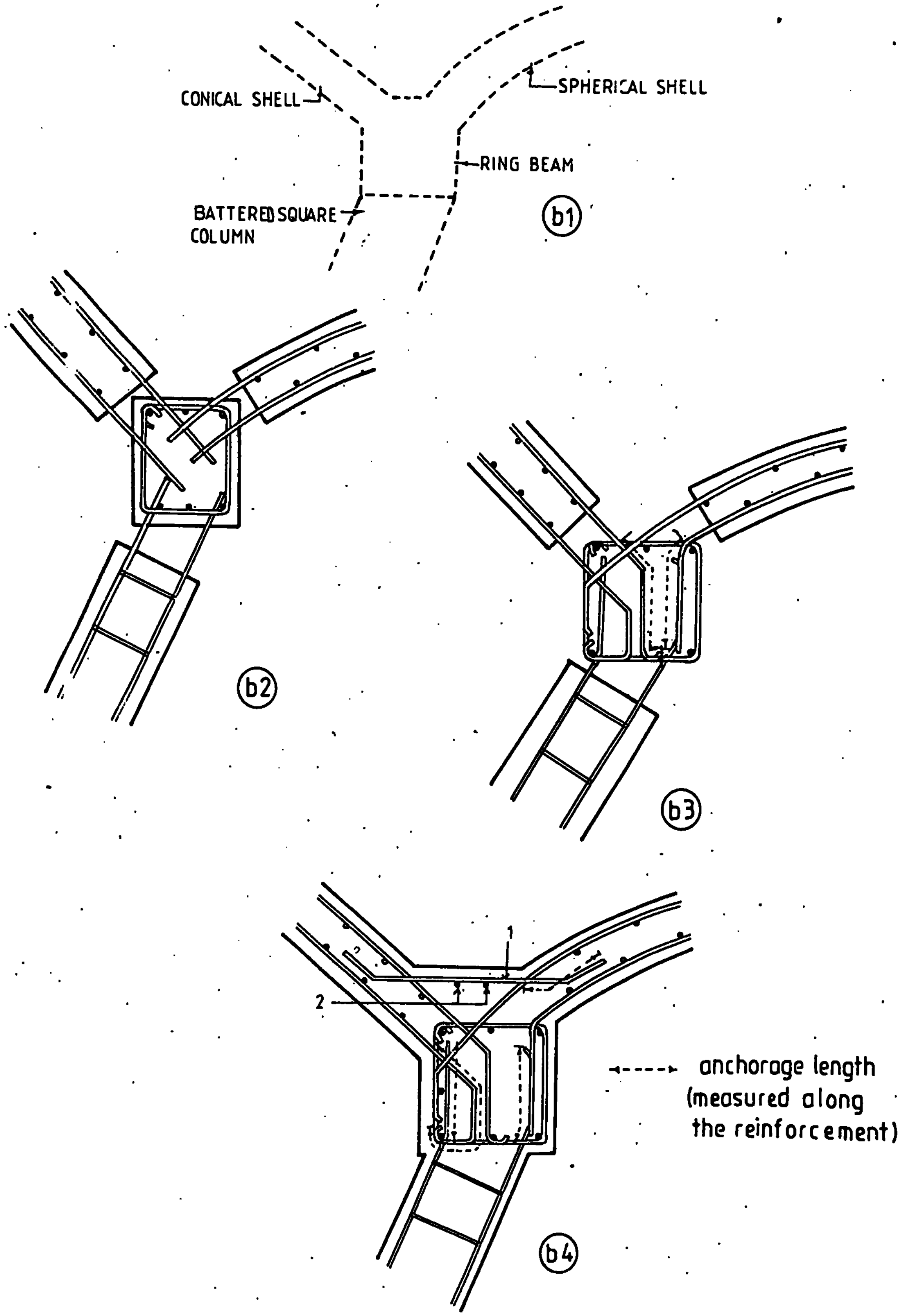


Figure 9 - Various stages of detailing in example 2.

9.0 References

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