SESSION A - ASPECTS OF DESIGN

LECTURE A6 - CROSS-SECTION DESIGN **PRESENTER: CD SCOTT**

1 INTRODUCTION

There is a tendency, particularly amongst road authorities and township developers but sometimes shared by designers, to consider the cross-section as a unit, whole and indivisible, in much the same way that the corridor, the horizontal alignment and the vertical alignment are units. As a result, the designer can find himself in the situation whereby the road reserve width is fixed by someone other than himself prior to design of the cross-section.

In the case of the road authority, the road reserve has a status enshrined as a result of years of court cases and legislation. Attempts to secure a wider reserve in order to accommodate some feature of the road function are thus met with some resistance. An ability to accommodate all the required functions in a lesser width does not result in the road reserve being made narrower and the statutory width remains in force.

The developer has an economic incentive to keep the road reserve as narrow as possible. In fact, two incentives apply. In the first instance, a narrow reserve forces the designer to adopt a cross-section containing the minimum of features, including narrow lanes and sidewalks, no provision for parking or, alternatively, parking beyond a mountable kerb in the area which would normally be reserved for pedestrians. A mountable kerb also costs less than a barrier kerb. The cost of development of the road reserve is kept as low as possible by any device that the developer's imagination can suggest. The extent of surface area dedicated to the township street system also dictates the availability of saleable land. Streets can occupy as much as a quarter of the total land area of the township and there is a correspondingly strong desire to reduce street area as far as possible. An over-designed street system thus not only costs more but it reduces the likely income from the sale of stands. The designer will thus be told by the town planner that a certain part of the street system shall have a road reserve no wider than a specified amount.

In both cases the designer find himself in the situation of starting from the answer and working backwards. A more logical approach is to determine what is required in the cross-section and then, as result of this provision, to determine what the road reserve should be. Although more logical, the restraints brought to bear on cross-section design are so overpowering that a degree of compromise is essential.

The unpleasantness of compromise is however alleviated to some extent by the fact that the cross-section is not a unit. It is a composite of many elements having different functions, shapes and dimensions. Cross-section design is thus not so much a case of calculation as a reasoned approach towards selection and locating of elements in the available width to ensure that the function required of the road is met.

2 ROAD FUNCTION

Road function has already been discussed in terms of a spectrum of needs ranging from dedication to accessibility to exclusively mobility, from the residential street to the freeway. It has also been described in terms of the fact that a road can be an inter-regional, intra-regional, hinterland or farm-to-market link. Finally, the road may be dedicated to some function other than movement.

The trip type to be served by the road has also been considered. Should it be addressing the home-based work trip, a recreational trip, or any other? Finally, thought has been directed to the fact that any trip can be subdivided into various components being initiation at a terminal, collection, the through portion, distribution, and termination.

A common feature of these considerations is that they largely revolve around addressing the needs of the occupants of a moving vehicle within the limitations of the vehicle. These needs may find expression in a desire for ready access to or from a property adjacent to the road, freedom to manoeuvre in a terminal or intersection area, high-speed long-distance travel and all such road uses. And these desires are to be met in terms of overall objectives of safety, economy and minimum side effects. Ultimately, however, the vehicle has to stop.

The scale of design reduces from vehicle size to human size. The pedestrian (defined as a motorist who has found parking) also has desires to be met in terms of safety, convenience, and a pleasant environment for walking in addition to the fact that a now slow speed of travel suggests that distances should be kept short. Furthermore, travel should be as directional as possible and with a minimum of height changes as manifested by the practice of crossing a freeway at grade in preference to using a pedestrian bridge or subway.

Road functions also have to include consideration in terms of living space. People enjoy the casual encounter, meeting people on neutral territory as it were and without the formal obligations imposed by having to act as host or hostess in the home. Chatting with the neighbours in the street is a case in point. Children riding their bicycles or skateboards naturally gravitate towards the street. To a child, cricket in the street is more of a practical proposition than on the front lawn where a plate glass window may serve as a sight screen and being hit for a six takes on new meaning.

The Woon-erf concept can thus come into play. In lower income residential areas, individual properties are small and cannot accommodate the recreational needs of the residents. The street therefore can fulfil a real need by becoming part of their living area.

Road function is thus more than just a device aimed at definition of design hour, design speed and design vehicle, ultimately dictating the route and the horizontal and vertical alignment. In determining the cross-section, the designer is forced to consider not only vehicular needs but also a broad range of human aspirations. These aspirations include the need for a pleasant, safe, harmonious environment for the community at large as well as the desire of the developer to show a profit. The latter should not summarily be dismissed because, without a profit, the developer ceases to be one and a lot of houses don't get built, leaving a lot of people on the street.

A road may be required simultaneously to serve conflicting needs. Residential stands abutting a higher-order mixed usage street are a case in point. The designer thus has to assess which of the functions should take precedence and design accordingly, thereafter providing minor modifications or additions aimed at serving the subsidiary functions. In terms of throughput of traffic, this is a less than ideal arrangement because the situation can arise whereby a single road is serving a multiplicity of functions, all of them poorly. However, the intention is not necessarily to maximise the efficiency of a link in the road network but to optimise the ‘liveability’ of the entire area. A strong argument could thus be made out for major reconsideration of the network as part of the overall optimisation process. This argument could however be countered by the fact that the existing situation may represent a considerable financial outlay and should not lightly be tampered with.

In a new or developing area, the designer should attempt to avoid multi-purpose roads where there isn’t a guiding predominant function. These tend to result in hybrid cross-sections and, like most compromises, they end up doing nothing particularly well.

Functions may change along the length of a road. A lower order mixed usage street may become a higher order street residential street may become a collector and ultimately grow up to be vehicle-only route. This process, and the different needs manifested along the way, may suggest that the route, as initially determined, should not have been sufficiently long and continuous to acquire all these functions. Route continuity is not necessarily an objective to be pursued at all costs and it may be advisable to consider the application of deliberate discontinuity.

By way of summary, the movement functions that the road must be able to accommodate include service to:

- vehicular traffic in terms of through or turning movements and provision for stationary vehicles which may be parked or stopped, the latter including queuing and the loading or off-loading of freight or passengers;
- other traffic, which includes pedestrians and could include other forms of wheeled vehicles such as bicycles, prams, wheelchairs and animal drawn wagons;
- public utilities, such as electricity, water, telephone lines, gas and sewerage;
- stormwater drainage of the reserve itself which can be longitudinal or transverse and above or below ground level including the transition from the one to the other; and
- stormwater drainage of the catchment area

The last three items were not discussed above but should be self-evident. Typical cross-section elements are illustrated in Figure A6.1.

Apart from the need for the horizontal and vertical alignment to be designed with safety in mind, certain elements have to be built into the road specifically to enhance safety. Vehicular safety will call for lane markings and refuge for turning traffic. Collision containment may involve longitudinal barriers or impact attenuation. Pedestrian safety requires barrier kerbs. Pedestrian crossings may have to be signalised and, when wide streets have to be crossed, some form of central refuge should be provided.

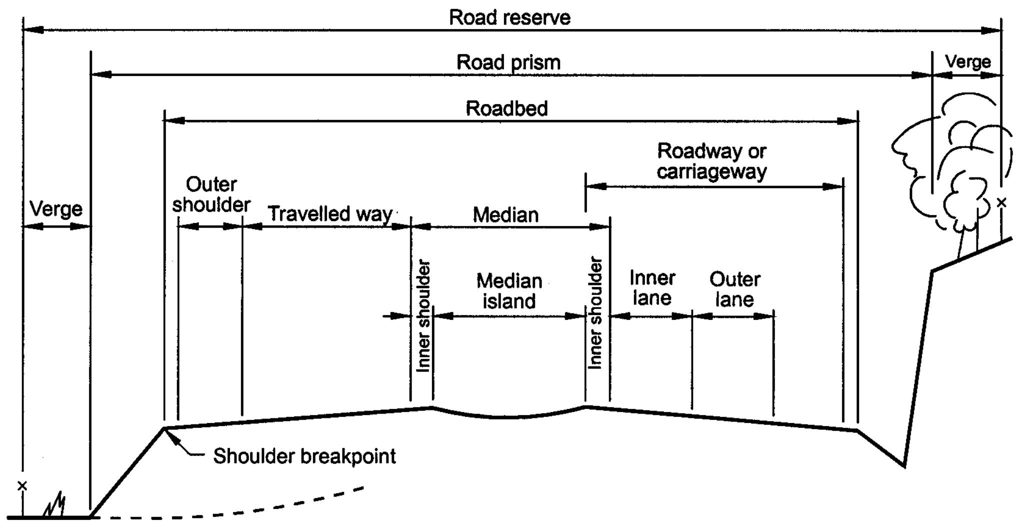

Figure A6.1: Typical cross-section elements

Pedestrian safety does not only concern protection from vehicles but also protection from other pedestrians. Muggings in subways are a case in point and can be minimised by proper design of the subway. Crime operates at its best in the dark and street lighting can thus be a disincentive for the average mugger. Provision has to be made for street lighting, specifically the location of the light poles so that the street is decently illuminated without the driver being confronted by a forest of poles that have to be avoided.

All the elements listed in the preceding two paragraphs form part of the cross-section and it now remains to establish the means of their accommodation.

3 CROSS-SECTIONAL ELEMENTS

3.1 Traffic lanes

The most obvious element in any cross-section is the traffic lane. A distinction is drawn between basic lanes, which are continuous from end to end of the route, and auxiliary lanes, which are provided to address a specific need and are discontinued once the need has been met.

Auxiliary lanes can be through lanes, i.e. in the direction of travel of the route. These may be required to match the capacity of an intersection with that of the route segment between intersections. They may also be required to remove slow moving vehicles from the traffic stream on a gradient, in which case reference is to climbing lanes. If traffic volumes do not warrant a climbing lane for the full length of the grade, partial climbing lanes also known as turnouts and passing bays could be employed. It is possible that traffic volumes are sufficiently heavy to cause platoon build-up. These platoons can be dissipated by use of passing lanes, typically 500 m long. Passing lanes are often provided initially at about 8 km intervals so that as a greater need arises, additional lanes can be provided reducing the interval to 4 km and ultimately to 2 km. The logical next step is to upgrade to a 2+1 cross-section.

Auxiliary lanes can also be provided to accommodate turning movements. These have the effect of removing turning traffic from the through lanes at through lane speeds so that a minimum of impedance is brought to bear on through traffic resulting in improvement of the capacity of the road. They also have safety implications insofar speed differentials are reduced. These auxiliary lanes typically have three or four separate elements being a deceleration lane, followed by a storage area or possibly a turning roadway, followed in turn by an acceleration lane. The deceleration and acceleration lanes typically commence and terminate respectively with a tapered section, with the degree of taper dictated by the speed at which the vehicles are supposed to transfer from basic lane to auxiliary lane and back.

The designer must select the number of basic lanes required to serve anticipated traffic volumes, and then consider each portion of the road to determine whether or not auxiliary lanes are required and for what purpose. A determination must be made of the required lengths of auxiliary lanes and thought given to the design of their terminals.

Selection of lane width in the case of basic lanes is based on considerations of anticipated speed, where higher speeds required wider lanes, and traffic volume. High volumes also require wider lanes because vehicles tend to shy away from each other. Narrow lanes are therefore compensated for by creation of longer longitudinal gaps in the parallel streams causing a drop in density and hence capacity. Prior to metrication, South Africa had lane widths ranging from 10 feet to 12 feet and, when we metricated, we opted for widths of 3,1 m, 3,4 m and 3,7 m. The Americans, in metricating their Green Book in 1994, adopted 3,0 m, 3,3 m and 3,6 m. The extra 0,1 m that we stuck on was to allow for road markings. Some urban authorities use lane widths of 5,0 or 5,4 m to allow for parking alongside the moving traffic without having to demarcate parking bays as such. These latter widths cause passenger car drivers to use a single lane as a double lane. In the peak hour in Pretoria, it is rather smart to signal your intention to move from one side of the lane to the other side of the same lane.

In the case of low volume roads, the need to maintain constant movement of two opposing lanes of traffic reduces. McDonald and Robinson refer to a carriageway width of 5,0 m with 1 m shoulders as being adequate for traffic volumes of 100 to 400 vehicles. They believe that a width of 3,9 m plus 1,5 m shoulders is adequate for volumes of 20 to 100 vehicles per hour and, for less than 20 vehicles per hour a total roadway width (including shoulders) of 2,5 m to 3,0 m is adequate.

If auxiliary lanes are intended to serve as through lanes at an intersection, their width should match that of the adjacent through lanes because speeds in these lanes could be similar. Turning lanes can be narrower because speeds are lower and turning flows also not always high. However, at the point at which the turning manoeuvre is actually performed, the lane will have to be widened - especially if it is separated from the adjacent traffic lanes by means of an island, in which case reference is made to a turning roadway. If not separated from the adjacent lanes, and volumes on the crossing street are low, encroachment on these adjacent lanes can be considered.

Special purpose lanes are very useful adjuncts to the designer's repertoire. A combination of restricted reserve width and heavily tidal flow could perhaps be accommodated by reversible lanes. Tel Aviv has an unusual arrangement whereby the CBD street system comprises one-way pairs except for taxis, who have dedicated reverse flow lanes. The taxi is definitely the fastest way to get across town even without allowance for the sheer joie de vivre that the average Israeli taxi driver brings to bear on his mission in life, which is to scare the living hell out of American tourists. Mass transit may suggest the dedication of lanes to high occupancy vehicles, an example being the bus lane. Heavy right turning flows could suggest common two-way continuous turning lanes for a portion of the route. The median lane has not yet been used in South Africa but has been widely adopted in the United States.

The number of lanes provided is typically a multiple of two although, in developing and residential areas where traffic volumes are low, a road may have only one lane with passing bays provided at intervals. The designer must then decide how long the passing bays should be and what the spacing between bays should be.

3.2 Shoulders

The shoulder is at the same level as the traffic lane. It can be applied to many purposes, including roadside vending, but the principal intention is that it should cater for emergency stopping. Shoulders may be gravelled or surfaced, and in the latter case, they also serve as informal climbing or passing lanes. In certain instances, traffic is allowed to use the shoulder as a through lane during peak hours.

Shoulder width can be anything from 1,0 m to 3,0 m and the selection of width is largely predicated on traffic volumes in the adjacent lane. If volumes are low, the fact that a stopped car is partially encroaching on the lane is not critical. On the other hand, with high flows, any form of encroachment at all is unacceptable. If flows are as experienced on freeways, the driver would not be able to get out of his vehicle if the shoulder width were less than 3,0 m.

This reference to width is specifically to usable width. If a need for guardrails arises, additional provision must be made for these usually by increasing the distance to the shoulder breakpoint by 800 mm, which allows 300 mm between the guardrail face and the edge of the usable shoulder with 100 mm behind the back of the guardrail post. Traffic signs are usually mounted beyond the shoulder breakpoint.

In the case of divided roads, the median comprises a median island and two inner shoulders and the latter are often as little as 1,0 m wide although, ideally, their width should match that of the outer shoulders, this ideal seldom being realised because of financial constraints.

3.3 The median

The application of the median was first mooted in the mid-Thirties as "a central island separating the up- and the down-traffic", a function which it admirably fulfils to this day. In addition to reducing the friction between opposing flows and also the likelihood of head-on collisions although the cross-the-median accident is not unknown, it also makes it possible to reduce headlight glare by plantings.

As illustrated in Figure A.3.2, the median makes split grading - where the two carriageways have independent gradelines - a possibility. The height difference that can be achieved is dependant on the median island treatment, ie as a natural slope or as a retaining wall. In the former case, the width of the median island and a maximum side slope of 1: 1,5 with allowance for a side drain on the lower carriageway will limit the height difference to about 3,0 metres.

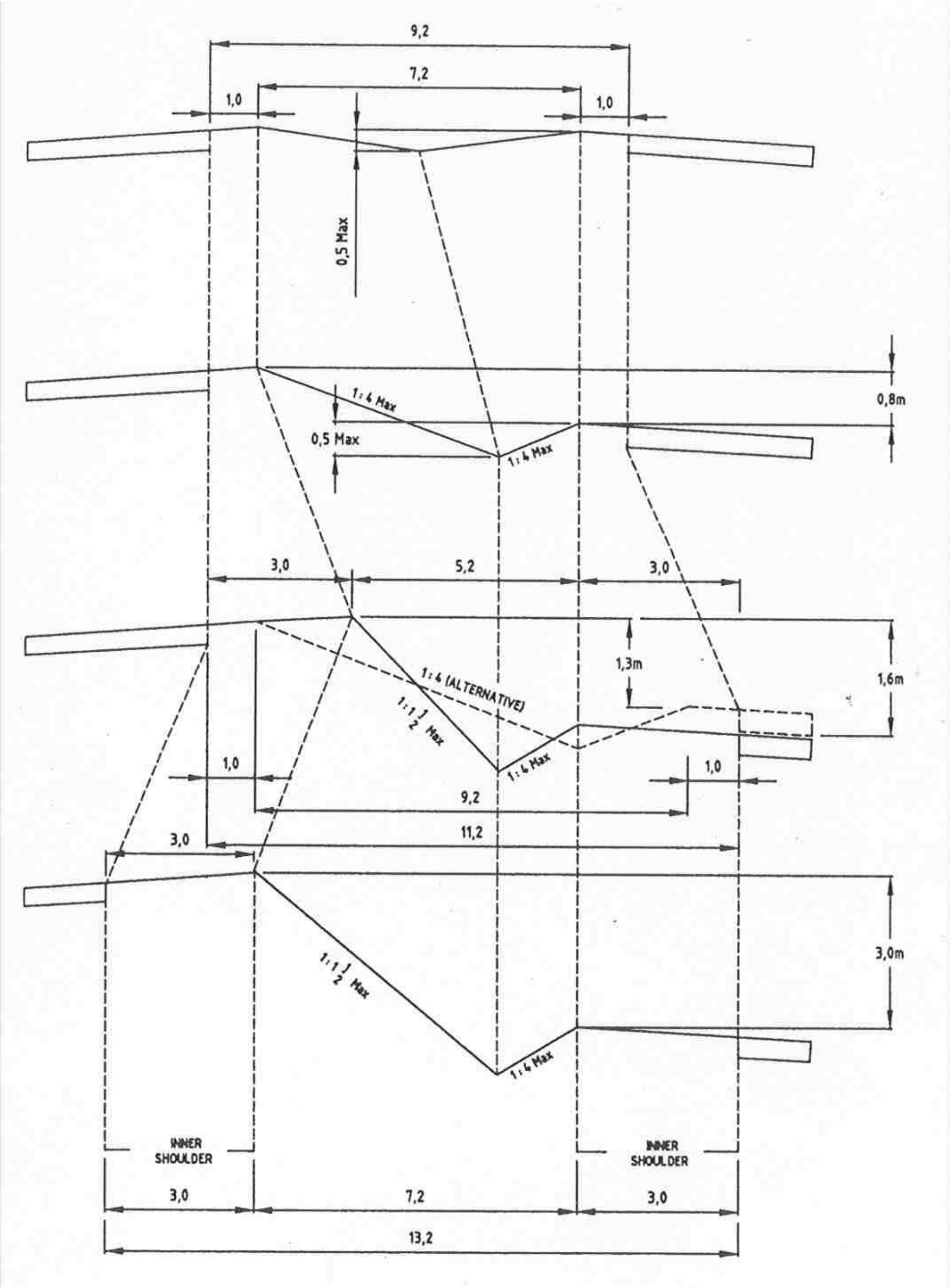

Figure A.3.2: Transition from single to split grading

Crossing a multi-lane highway on foot can be a terrifying experience particularly in the South African situation, which suggests that pedestrians achieve invisibility the moment they step off a sidewalk. The median provides a useful central refuge.

Provided it is sufficiently wide, the median also can offer refuge to turning vehicles by accommodating a right-turning lane within its width.

A wide median is often a stage in the development of a multilane road that may commence as four-lane divided. The most convenient site for widening is, in fact, within the median island.

Median islands have also been used to accommodate light rail facilities although this fairly exotic application can generate problems in terms of operation both of the road and the mass transit facility.

Selection of the width of the median is not a trivial exercise. Urban sprawl causes rural roads to become suburban arterials. If the rural road was a dual carriageway, the likelihood is that its median would have been of the order of 9,0 m or wider. This width becomes a problem when applied to an urban intersection. The travel distance for turning traffic is rather long and the signalised time that has to be made available for this traffic can cause the operation of the intersection to be inefficient with high delays.

Somewhere, the median has to end. Various end treatments are shown in Figure A6.3.

3.4 Outer separator

The outer separator occurs comparatively seldom but serves to separate flows where the road reserve is required to serve two disparate functions such as high speed through flow and local access. It can also be used to accommodate parking bays on the outer side, where a principally pedestrian activity is located at the edge of the reserve.

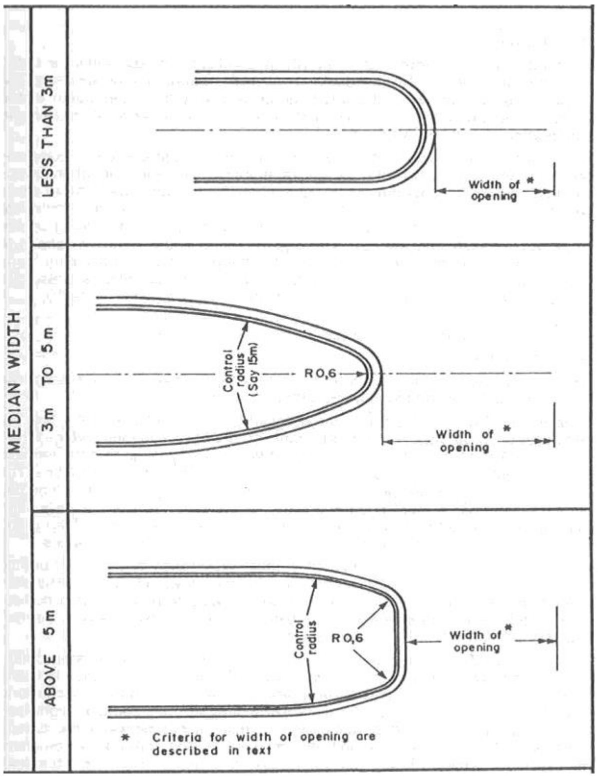

Figure A6.3: Typical median end treatments

3.5 Verge

The verge is the home for all the other activities that have to be accommodated by the road reserve. It is sometimes described as the area that is left over after the road has been provided although its width should actually be determined in a more precise fashion than this. Cycle tracks, pedestrian paths, landscaping and roadside furniture are all located in the verge, and it must also accommodate cut and fill slopes, or retaining walls under restricted circumstances. Access to adjacent properties in residential areas requires that a vehicle should be able to stop at right angles to the road without encroaching onto it.

Passengers boarding or alighting from buses stopped in the through lane can cause substantial queues to develop. A bus bay located in the verge, as illustrated in Figure A6.4, eliminates the problem entirely.

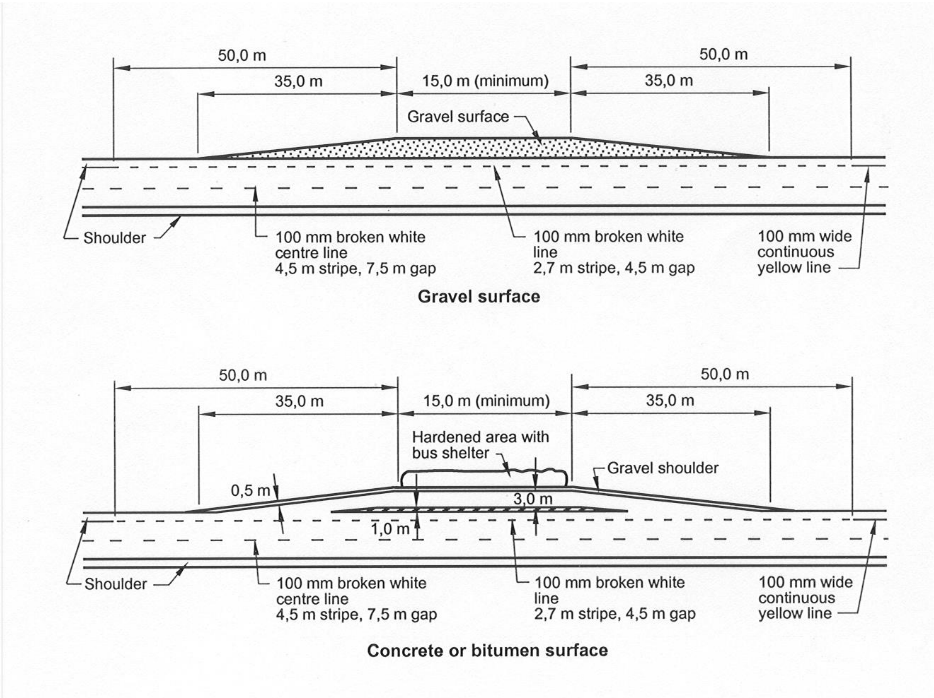

Figure A6.4: Typical bus bay layout

Utilities usually are accommodated under the verges. Spatial restraints sometimes require that they be placed under the carriageway. This is not a desirable state of affairs because manhole covers have to be lifted and reinstated every time the road is resealed. Routine maintenance places workmen at risk and the trenching that seems to be called for at frequent intervals results in a very uneven road surface.

With the exception of kerbing and channelling and the associated drop inlets, all storm water drainage is located in or under the verge. The elements that comprise the storm water management system are discussed in a subsequent lecture.

Reference should be made to the Red Book with regard to “hard open spaces” and the functions that they are intended to serve as these will impact on the design of the verge.

4 THE DESIGN PROCESS

There has been deliberately little or no reference to actual values of the dimensions of cross-sectional elements.

The intention has been to focus on the process whereby the designer commences with the broadest definition of road function and thereafter refines and fills in the list of specific objectives to be met in ever-increasing detail both across and along the length of the road.

The derivation of this statement of objectives makes it possible to consider how best they can be met. The designer must then consider all the cross-sectional elements at his disposal and make a selection of those that best address the situation. It is sometimes advantageous to also highlight those that would be inimical to the defined objectives, the example quoted previously being the median island on a residential access street, to ensure that these are deliberately excluded from the design regardless of any temptation that may present itself.

The selection of elements produces a rough, undimensioned sketch of the cross-section

The sketched cross-section is then dimensioned. These dimensions often derive from other studies, such as capacity studies indicating the number of lanes required for a given flow or the need for auxiliary lanes at intersections. Traffic flow analyses will indicate the extent of storage required for vehicles queuing to turn to the right or to the left.

The cross-section width is then summed and compared to the available road reserve width. The latter is likely to be a constant value whereas the cross-sectional width will vary all the time as different and conflicting demands are balanced out and met. Three possible outcomes have to be considered, being that;

- ❑ at no stage is the available width exceeded, or
- ❑ only at certain isolated points is the available width exceeded, or
- ❑ the available width is exceeded either for considerable stretches of the road or all the time.

In the first case, there are clear grounds for satisfaction.

The second case indicates that, by and large, the design can be considered acceptable but that some fine tuning may be called for, either by way of accepting the outcome of the design and seeking to obtain the extra territorial requirement or by re-examination of the design at the problem points. The design may perhaps be calling for some provision which, in fact, is not necessary, eg allowing 6 m in the verge for vehicular access to adjacent properties in areas where such access would not be encouraged, ie in the immediate vicinity of a high-volume intersection, introducing a saving of space. Another option may be to adjust non-critical dimensions to ensure that the cross-section is accommodated within the available space. For the occasion, lane and shoulder widths are NOT considered non-critical. The elegance of the solution arrived is limited only by the skill and imagination of the designer.

If the cross-section consistently does not fit the reserve, a major rethink is called for. It may be that the designer has been extravagant in his demand for lebensraum, or that the developer has been overly parsimonious in provision of space. If neither proves to be the case and no mutually acceptable accord can be arrived at, the designer has no option but to go back to the originally defined functions and prune everything back until as many as possible of the more important functions are met and the cross-section fits the reserve.

A decision is then required regarding the functions that are not met. Three possibilities present themselves:

(a) These functions are summarily abandoned.
(b) They are provided elsewhere
(c) The road is rerouted to the extent required to reduce the restraints so that all functions can, in fact, be supplied.

To illustrate:

A need for parking bays to serve an extended shopping area conflicts with a need for auxiliary lanes at successive intersections to the extent that it is not possible to accommodate both in the reserve. The options that suggest themselves are:

- ❑ to obtain adequate space by demolishing the fronts of the shops, which would end to remove the need for parking;
- ❑ dispense with the parking bays, which would probably sound the death knell for the local shops;
- ❑ to dispense with the auxiliary lanes, which would cause an unacceptable degree of congestion on the through route, also to the detriment of the local shops in addition to a penalty inflicted on through traffic;
- ❑ to reroute the major route altogether leaving the parking bays intact, but with the entire shopping area becoming a little and virtually unknown enclave serving only the residents in the immediate area and with lots of empty parking bays to the dismay of the shop owners
- ❑ provide off-street parking.

Where public participation is increasingly impinging on the activities of the geometric designer, he would have to discuss such problems not only with his client but with the local residents and shop owners as well. It deserves to be noted that, of all the members of the design team, it is the geometric designer who is most likely to be called upon to face inquisitions by irate ratepayers associations. In the above example, the shop owners, having survived the first four options, would be so happy about the last that they would provide the land required at little or no cost ....