LECTURE I3 – INTERCHANGE DESIGN

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Interchange Components

Despite their often complex appearance, interchanges comprise only four basic components, these being:

- **the through road**
- **the crossing road**
- **the structure(s) separating these two roads, and**
- **the ramps providing trafficable connections between them.**

The two roads are dealt with in the ordinary way for design, and they may even be existing roads with a grade separation, to which the interchange ramps are added.

Interchange Components

To the geometric planner, the principal concern regarding the structure would be the thickness of the deck. The geometric planner must liaise with the structural engineer in this regard, once he establishes a preliminary layout for the road crossing. Generally, a vertical clearance of at least 5,1 m would be required at the critical tie point.

It may be found, when one tries to add the ramps to the two crossing roads (whether these exist on the ground or only “on paper”), that the alignment of the two roads is not suitable for the grading of the ramps, say, or does not allow a suitable horizontal alignment to be fitted in for the ramp. The two roads then require adjustment, and the whole design exercise is usually an iterative process.

Interchange Components

Each ramp can be subdivided into two sub-components viz

- **the terminals, which are its connections to the through and the cross-road**
- **the mid-section**

As discussed in the lecture on Interchange layout, it is prudent to develop the configuration of each ramp separately, considering the traffic service it must provide, the traffic volume it must cater for, and the nature of the terrain and the available space.

Terminals

There are three forms of terminal that may be required. These are:

the free-flowing terminal used as the connection between the ramp and a freeway.

the stop-condition terminal which serves as the connection to a crossing road that has at-grade intersections elsewhere along its length, e.g. an urban arterial

the major fork and merge, both of which are free-flowing but differ from the free-flowing ramp terminal in that the latter attaches an inferior status to the ramp, where-as all the legs at a major fork or merge may be viewed as full freeway sections, not ramps.

Terminals

The free-flowing terminal is intended to accommodate merging or diverging maneuvers involving high operating speeds and small differences in speed between vehicles. These are thus executed at speeds matching uninterrupted flow conditions and involve flat angles of merging with or diverging from traffic on the through lanes, typically 1:15 in the case of freeway off-ramp terminals and 1:50 for freeway on-ramp terminals.

The relatively sharper taper for an off-ramp assists in giving target value to the exit, provided that the edge-line has a kink and is not rounded. The flatter taper of an on-ramp helps to make the relative speed between vehicles as low as possible.

Terminals

Whether on- or off-, the ramp terminal may comprise either a simple taper or a combination of taper and a section of auxiliary lane parallel to the through lanes. The latter layout forces a reverse curve line of travel on vehicles and is thus not universally favoured.

The freeway exit or entry maneuvers should be executed at freeway speeds. If, for any reason, ramp speeds are required to become substantially lower than freeway speeds somewhere close to the freeway terminal, it would be necessary to provide sufficient length of ramp for the necessary speed-change, to better match the ramp and the freeway speeds.

Terminals

Nose and Gore Areas

The ramp “nose” is commonly defined, (somewhat arbitrarily), as the point at which, after the ramp and freeway have diverged from each other, there is a separation of exactly two metres between their adjacent shoulder edge-lines. The same applies on the section before the merging area of an on-ramp.

The area between the two diverging shoulder lines is referred to as the “gore”. In the case of an off-ramp, the gore is the location of the last sign in the sequence of exit signs, confirming the exit number and having a chevron plus a horizontal “exit” arrow to draw attention to the exit.

Terminals

The nose, and the gore beyond it, are the major indicators of the commencement of the ramp. They must be highly visible. In previous years, the nose was demarcated by raised kerbing. The kerbing brought new meaning to the words "target value", and because of the hazard of such kerbs in the gore area, painted markings are now used exclusively. Decision sight distance to the exit nose is a requirement.

Stop-condition terminals are used when a ramp joins a crossing road which is not a freeway, although in the case of heavily trafficked major arterials, some form of free-flowing treatment (slip-lane) may be called for.

Terminals

These terminals are designed basically as ordinary intersections with one or two special conditions because the number of turning movements is generally limited.

Because of urban speed restrictions and also because of the design of the ramp itself, vehicle speeds at these terminals are low. Because of the stop condition, the relative speeds of the vehicles on the different approaches to such terminals are high. These terminals should thus intersect with the crossing road at angles of the order of $90^{0,}$ and be designed as conventional intersections.

Terminals

In reality, there is little need to accommodate a movement straight over the crossing road (coming from the freeway and straight back onto the freeway). The need could arise for three acceptable reasons, and should preferably be made possible:

- an abnormal load of excessive height that has to be diverted around a structure where the freeway passes under the crossing road
- the freeway being temporarily closed for maintenance work on the structure or by someone electing to drive into someone else or a bridge pier
- a driver being momentarily confused rather than totally lost and simultaneously aware of a quick way of reinstating his travel path along the freeway.

Terminals

A fairly recent form of the diamond interchange, the "Single Point Diamond Interchange" has all conflicting movements of the four ramps meeting on the cross-road in one large intersection.

The left turns at the ramp terminals are dealt with by slip lanes which separate these movements from the central intersection. The central intersection then deals only with right turns and with the straight-through traffic on the arterial. This normally has signal control which is said to operate very efficiently.

Terminals

Major Forks and Merges

The situation can however arise when the status of the merging or diverging carriageways is equal. Cases in point are where two freeways from outlying areas merge to share a common reserve on approaching the core area of a city, or where directional ramps split to become two ramps, one serving the left turn and the other the right.

These movements are accommodated by major forks and merges. Seeing that the legs involved are of equal status, the restriction regarding the use of the outer freeway lane does not apply.

Terminals

Geometry of Free-Flow Terminals

Two key aspects of the placing and design of free-flow ramp terminals are considered here. These are the spacing of successive terminals and the taper rates employed.

The spacing of successive terminals must be such that the operation of one terminal does not affect that of the adjacent terminal. An entrance terminal shortly before an exit can effectively be blocked to the entering vehicles by a large number of vehicles trying to exit at the next terminal. Space should be allowed for an adequate sign sequence.

Terminals

Free-flowing terminals can be either parallel or taper. The latter is a simple constant taper, and the former is a taper in combination with a short length of auxiliary lane. The lengths of parallel auxiliary lanes may relate to speed-change requirements and could be as much as 600 m or so.

Different criteria apply to the taper rate for an off-ramp or an on-ramp. The off-ramp must depart at a sufficiently sharp angle for it to be very clear to the driver that a discontinuity has presented itself. At the same time, the driver must be able to negotiate the change of direction at the operating speed of the freeway.

Terminals

A cross-fall of 2 % across the width of the carriageway and across the taper as well, would correspond to the super-elevation required for a curve of radius 280 m at a speed of 100 km/h. A vehicle can be contained within the width of the travelled way available to it while negotiating a curve of this radius if the taper rate is in the region of 1:15

At an entrance, the prime criteria are the driver's need to find a gap in the traffic in the outside freeway lane, and also the mechanics of visibility of approaching vehicles in the rear view mirror.

Terminals

It has been found that a taper rate of about 1:50 provides an adequate convergence length and is also effective in terms of rear view visibility for typical freeway speeds. The current SANRAL Design Guidelines now require specific taper rates for the various design speeds adopted for design purposes.

Over the length of the actual taper (from the start of taper to the point where the full ramp width is attained), the ramp terminal and the freeway through-lanes are designed with a constant cross-fall across their full width, right across to the ramp outside shoulder.

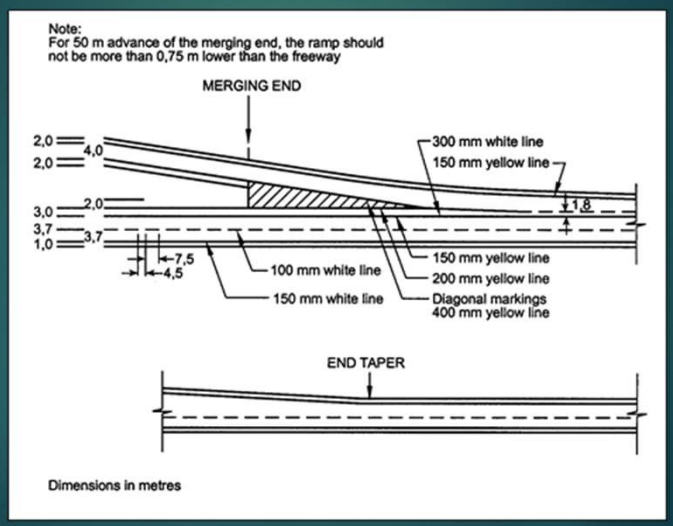
Terminals

The point at which the full ramp width is attained is referred to as where “edges meet”. The taper continues further at a constant rate (1:15 or 1:50) up to the nose which, according to a typical standard design, is where the taper is wide enough for the ramp plus both shoulders in the gore, plus two metres.

From this nose position it is permitted for the ramp to curve away from the fixed line of the taper off the freeway. From “edges meet”, a change in crossfall of the ramp may be introduced gradually by means of a slope change along the lane edges. This would form a “cross-over crownline” which is similar to the crown along the middle of a cambered road.

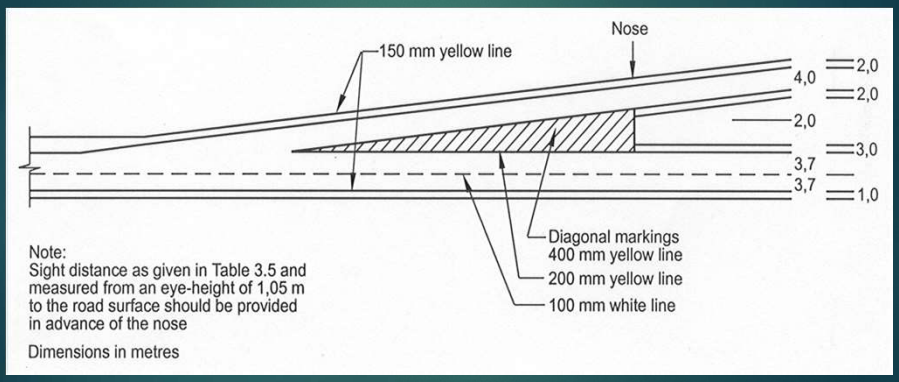
Terminals

Single Lane Entrance



Terminals

Single Lane Exit



Ramp Mid-Sections

Ramp terminals signal an immediate transition from the freeway or the crossing road to a changed circumstance. The ramp mid-section offers the driver time to adapt from one operating environment to another. The uninterrupted long distance and high speed of the freeway desensitises the driver to speed, to an extent whereby travel at 60 km/h may seem to be only marginally faster than getting out and walking.

Conversely, the driver on the crossing road needs a little encouragement to adopt the higher speed of the freeway.

Ramp Mid-Sections

The length of the mid-section depends on various factors such as gradient and curvature and including the extent of speed change required on the ramp. The off-ramp requires deceleration across the range from freeway speed to cross-road operating speed including possibly allowing for a stop at the crossing road. It is presumed that this deceleration will commence only after the nose has been passed.

The on-ramp must allow for acceleration at a rate of say 1 m/s^2 to achieve freeway speed at the merging end. This rate is predicated on a level grade. Positive gradients will force a lower rate of acceleration and negative gradients allow a higher rate with corresponding change in the required length.

Ramp Mid-Sections

Ramp mid-Section Geometry

Design speed as applied to ramp mid-sections will vary along the length of the ramp, ranging between that of the freeway and that at the crossing road. For a simple, reasonably directional ramp such as in a diamond interchange, the variation can be a roughly uniform reduction or increase depending on whether the ramp destination is the crossing road or the freeway.

Where the crossing road is also a freeway, the design speed of the ramp should theoretically be that of the adjacent freeways. In practice, spatial restrictions will make some reduction necessary, but this reduction should not be more than 20 % of the freeway design speed.

Ramp Mid-Sections

Ramps serving right turns may do so by means of a 270^0 change of direction (i.e. loops). To achieve this at freeway speeds would demand a king's ransom in terms of land acquisition. Think of a cloverleaf interchange with a reserve width measuring 2 km by 2 km!

In general, a design speed of 40 km/h is adequate for loops because the advantages of a higher design speed will generally be nullified by the additional travel distance involved.

As the free-flow terminal must operate at freeway speeds, the mid-section between the taper and the minimum loop radius may require a compound-curve approach.

Ramp Mid-Sections

Recommended design speeds for semi-directional or directional ramps are thus not very much less than the through-road speeds

Diamond ramps and Par-Clo ramps usually have a free-flowing terminal at one end and a stop-condition terminal at the other. The free-flowing terminal and adjacent section of ramp should have a design speed equivalent to the operating speed of the through road. From the nose area it may be reduced progressively according to the distance from the nose, and the gradient.

Ramp Mid-Sections

Under certain circumstances, it is necessary for the driver to be able to see the actual road surface for a given distance ahead. The required sight distance is then measured from the standard eye height of 1,05 m to an object height of zero, i.e. on the road surface. The sight distance must be sufficient to see the road markings and then make the corresponding decisions about vehicle path or speed change and is referred to as **decision sight distance**.

Ramp Mid-Sections

The minimum radii of curvature used are calculated from maximum rates of superelevation and the maximum allowable side friction appropriate to the design speed selected. They are the same as those quoted for curves on other sections of road as well, because the fact of the curve being on a ramp does modify the dynamics, nor the calculation.

Interchanges must often be designed in the smallest possible space, and there may be little room for the desired length to develop superelevation. The rate of development may be increased slightly (up to 20%) over that applicable to a two-lane road

Ramp Mid-Sections

The derivation of the vertical alignment is generally based on the individual grading of each ramp edge rather than defining a single gradeline and a rotation about it. In this way, the superelevation and its development becomes an integral part of the vertical alignment.

Gradients steeper than those specified for other roads may have to be accepted on ramps, on the basis that the affected travel distances are short. Also, steep up-gradients on off-ramps and steep down-gradients for on-ramps can be advantageous in terms of the reduction in distance required for speed changes.

Ramp Mid-Sections

Vertical curvature is based on sight distance. The normal object-in-the-road model does not always apply because much of the information that is to be conveyed to the driver is transmitted by way of road markings, requiring a zero object-height.

Access ramps are generally single lanes. Directional ramps can be long however, with a correspondingly high probability of vehicles being forced into platoons on the ramp. Two-lane operation then becomes necessary. At the cross-road ramp terminal, the cross-section is designed as for an at-grade intersection, frequently with multiple lanes.

Ramp Mid-Sections

In the mid-section of the ramp, the need to pass stalled vehicles becomes a consideration, and on long directional ramps, the need to pass slow or stalled vehicles likewise.

Lane widths are thus selected to allow for passing of a stalled vehicle. A typical cross-section is a four-metre lane with shoulders of two metres width on either side. Two-lane cross-sections use lane and shoulder widths matching those of the freeway, with allowance for curve widening if radii are very short.

Ramp Types

It is convenient to name ramp types according to the interchange configurations in which they typically occur.

The **diamond ramp** has a free-flowing terminal at its freeway end and an at-grade intersection, or stop-condition terminal at the far end. The at-grade intersection allows for turns both to right and to left and, in urban areas, is frequently signalised.

The **Par-Clo loop ramp** may be compared in operation to a diamond ramp, noting that its stop-condition terminal is on the far side of the crossing road.

Ramp Types

The **directional ramp** is to serve right turning traffic and has free-flowing terminals at either end. This type of ramp typically encountered on a systems interchange, and is designed for high speeds as well as high volumes.

Outer connectors are equivalent to directional ramps in terms of the general appearance of their horizontal alignments except that they serve the left turn. They have high speed terminals at each end, nd do not require separating structures as they do not cross the main roads.

Ramp Types

Collector-distributor roads (C-D roads) came about when weaving between loops of a cloverleaf became a problem. The idea of the C-D road is that the weaving manoeuvre is removed from the freeway and allowed to take place on the parallel C-D facility. The C-D Road is linked to the outer connectors, with a terminal design according to the requirements for a major merge or fork.

The **quarter-link** is a type of ramp used at an interchange between two arterial roads, and specifically does not occur in any interchange with a freeway. It is typically a two-way road with conventional intersections as terminals at each arterial road.