LECTURE I2– INTERCHANGE PLANNING & LAYOUT

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Introduction

The geometric designer who has never had occasion to design an interchange may think that he has somehow been left out of a rather exclusive club. Probably true. There are not that many interchanges in South Africa any way, so that relatively few designers have been afforded the opportunity to exercise this fascinating form of design, which may be described as a three dimensional jigsaw puzzle.

In fact, an interchange is nothing more or less than a rather sophisticated intersection. In certain instances, it becomes a *very* sophisticated intersection, but an intersection it remains, and it is done according to all the basic principles of road design and intersection design.

Introduction

The very first interchange ever was designed in New Jersey in 1928. The resulting layout looked like the four-leaf clover which then gave its name to this interchange type. The cloverleaf is considered by some to be the least successful of all interchange layouts. One advantage of the cloverleaf is that if you have missed your left turn, you can replace it by three successive right turns!

A potential weakness of the cloverleaf is the weaving that it may generate, depending on the traffic patterns. Another drawback of the cloverleaf is its relatively large territorial needs.

The Application of Interchanges

Control of Local Access

The spectrum of road functions ranges from accessibility to mobility, and the freeway is at the extreme end of the spectrum. It is concerned purely with mobility and has complete control of access. Access control is one of the prime definitions of a freeway, and access is allowed only at interchanges. If the interchange is with a local road or street, the interchange will serve an access function and is thus termed an “Access Interchange”.

The crossing road would, or should, be a major road in the local network.

The Application of Interchanges

An interchange has “ramps” which link the crossing roads. The start and end of a ramp are known as the “ramp terminals”. In an interchange, the ramp terminals at the crossing road could also be at-grade intersections, hence matching the characteristics of the rest of the route. The ramp terminals with the freeway require high speed, flat angle merging which calls for tapers.

The familiar “diamond” layout is the most often used example of the access interchange, although other access interchange forms will be discussed below.

The Application of Interchanges

Connection between Freeways

It is likely, particularly in urban areas, that a freeway will be one link in a system of freeways. Interchanges will then provide the connections between the various freeways and are therefore referred to as "Systems Interchanges".

Since both the crossing roads through such an interchange are freeways, the terminals at both ends of a systems interchange ramp are high-speed tapers. Freeway speeds and traffic volumes are generally high, so that a common feature of systems interchanges is the "directional ramp" for right turns.

The Application of Interchanges

Spatial versus Temporal Separation of Traffic

Where two heavily trafficked arterials intersect, even the most enterprising exercises in multi-phasing, signal synchronisation, use of auxiliary lanes etc. may all fail to provide sufficient green time for the number of vehicles that have to traverse the intersection area. Traffic signals provide a separation of traffic streams in time, "temporal separation".

The grade separation is the medium whereby that spatial separation is brought about. The moment that links between the two arterials are added, the grade separation has been replaced by an interchange.

The Application of Interchanges

Topographical Considerations

In a previous lecture, some thought was dedicated to the location of intersections and specifically to the places where intersections should not be put. What then, if the problem is that the logical gradelines of the two roads at the intersection site are separated vertically by several metres?

There is not necessarily only one answer to this problem. The options to be explored include dropping one gradeline into cut, raising the other onto fill or a compromise involving both gradelines.

The Application of Interchanges

All three of these options may involve regrading over substantial distances with commensurate earthworks costs, apart from any penalties in terms of sight distance that may be involved.

The fourth option is an interchange. If topography is the only reason for the interchange, ie traffic volumes are light and access control is not a restriction, it may be possible to consider the quarter link layout which consists of a grade separation structure and a single two-way ramp with at-grade intersections at both ends.

Principles of Interchange Design

At the outset, one should remember that an interchange, like the cross-section, is not something that is whole and indivisible. It comprises several discrete components. Each need that the interchange has to serve should be considered and the individual interchange component that is required to serve that need should be selected.

In the Eighties there was a shift in emphasis towards considering the basic operational principles that govern the selection of interchange type. These principles are based in part on the human factors governing design. The major causes of driver error are:

Principles of Interchange Design

- Excessive task demands
- Unusual manoeuvres or task requirements
- Poor sight distance
- Expectancy violations
- Information displays that may be missing, ambiguous, misplaced, obscured or inconspicuous.

The following operational considerations should be followed by the designer in developing the interchange layout.

Principles of Interchange Design

Basic Number of Lanes and Lane Balance

The concept of **basic number of lanes** is simply that there should be a clear indication to the driver that what he/she is driving on is a two or three or more lane carriageway. These basic lanes must continue to exist for a substantial length of freeway. This also implies that the basic number of lanes should be provided through an interchange.

The fact of the matter is that basic lanes should not be picked up or dropped off in willy-nilly fashion.

Principles of Interchange Design

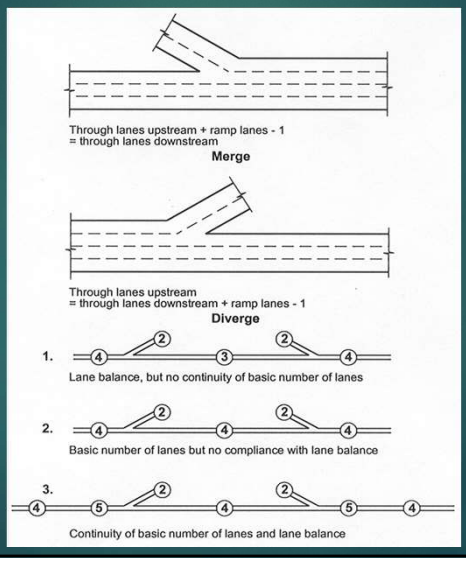
Lane Balance

Lane balance requires that the total number of lanes downstream of an off-ramp (i.e ramp lanes plus freeway lanes) be one more than the number upstream (i.e. freeway lanes only) and the number of lanes downstream of an on-ramp be one less than the total upstream

The designer who creates a lane imbalance, can cause a freeway driver to imagine that he is on a through lane, and then have him carried off inexorably down an off-ramp into the bowels of a suburb that he had no intention of visiting.

Principles of Interchange Design

The principles of lane balance are illustrated thus



Principles of Interchange Design

Route Continuity

An unfamiliar driver entering a freeway system say to the north of an urban area and wishing to continue his journey beyond the city towards the south would not be well served if his travel path required picking up a cross-link to another roughly parallel freeway some distance to the east or the west.

Logical routes should thus be defined to be continuous or at least provide the illusion of continuity during the planning of the network. (Follow the Route Markers!).

Principles of Interchange Design

Appropriate Form

Appropriate form relates to the fact that the designer should not decide in advance that the next interchange coming up should be a Par-Clo, say, just to give some variety from the previous three diamonds.

Appropriate form relates to the function and movements that the interchange is intended to accommodate and their relative volumes.

Clearly it is necessary to design the components to suit the individual traffic movements and then to assemble these components. This process determines what the form of the interchange is.

Principles of Interchange Design

From above, appropriate form was related to function, and this also means that one shouldn't have the function and form of "access" and "systems" interchange components mixed up in a single layout.

The R21/R24 Interchange at Johannesburg's OR Tambo International Airport is an unfortunate demonstration of such interchange schizophrenia. It is essentially a three-legged systems interchange that, in a very confined space criss-crossed by railway lines, also had to accommodate access legs serving the airport and a local street.

Principles of Interchange Design

Reduction of Weaving

A potential weakness of the cloverleaf for example is that it can generate a substantial volume of weaving between loops, which has to take place within a very short distance and often in the relative darkness under the structure.

Weaving also takes place between interchanges and not just within them. If the interchanges are spaced too closely together, the problem of turbulence can cause the entire freeway operation to hit Level of Service F even if the actual volumes suggest that a far higher LOS should be prevailing.

Principles of Interchange Design

Left-Side Entrances and Exits

In the early days of freeways, drivers had difficulty in realising that, if they wanted to exit a freeway with a view to travelling towards the right, it was first necessary to leave the freeway on the left. Similarly, a driver on the crossing road wishing to enter the freeway to travel towards the right, would joyously dive down the first hole that he saw.

The more practical problems with right-hand exits are the speed differential that results from having vehicles exiting from what is effectively the fast lane, and finding the space in the median for including a lane that can climb up and over the opposing carriageway.

Principles of Interchange Design

Single Exits per Interchange

We have already discussed the problems that drivers experience with thinking. When a person is confronted with a multiple-choice decision and has little time to make up his mind, the likelihood of error increases dramatically.

The reason for having the exit in advance of the structure relates to visibility, and the fact that a left turn, in any event, is better served by an exit upstream of the crossing road. Seeing the exit ahead of a bridge makes it clear that this not just a grade separation, and the required width of bridge opening is also generally smaller and less costly, with the advance exit

Principles of Interchange Design

Simplified Signing

A standard bit of dogma trotted out by older designers is "If you can't sign it - don't design it." Once again, the R21/R24 Interchange serves as an example of insufficient space for timely sequential signage. A reading rate of hundreds of words a minute is required, in addition to hair-trigger reflexes

The driver, whose only desire is to stay on the road, not get hit by other vehicles, and to end up going in the right direction, simply doesn't have the time to decipher elaborate instructions.

Driver Guidance

Drivers do get lost on freeway systems. Invariably this is because the system is unfamiliar to them, and they did not do their homework with maps in advance.

A driver travelling at high speed in an unfamiliar area, concentrating principally on the quirks and idiosyncrasies of the surrounding driver population could quite easily overlook the odd helpful road sign. Correct interchange design can however offer useful guidance, allow space for clear signage and substantially ease the driving task.

Driver Guidance

Target Values of Interchanges

A bridge crossing over the freeway can be seen from a considerable distance ahead. It offers the driver advance warning of the fact that an interchange may be coming up and he can thus give some attention to his navigational task and be alert for directional signing.

From this point of view, the argument of "Over versus Under" favours the crossing road at an interchange being over the freeway. An operational benefit of this configuration is that the off-ramp has a positive gradient which eases deceleration and the on-ramp a negative gradient assisting the driver to reach the freeway speed more easily.

Driver Guidance

Standardisation of Ramp terminal Treatment

By consistently placing the noses of off-ramps in advance of structures and the merging ends of on-ramps beyond structures, regardless of the appearance of the rest of the ramp, the driver will be provided with some foreknowledge of what to look for in navigating his way around the system.

The phrases “design consistency” and “driver expectation” have frequently been used in these lectures and they apply at least equally to interchanges. Of course, the standard “count down” signs placed at 300, 200 and 100 metres before the exit have proved to be a great help.

Interchange Layout

After the very first clover-leaf interchange an assortment of interchange layouts proliferated, with some “lunatic fringe” layouts also being generated along the way.

Diamond Interchange

The Diamond is perhaps the most frequently occurring layout for access interchanges. It is a simple layout with direct ramps that are relatively safe with proper design. It has stop or signal control at the cross-road ramp terminals and is used to provide access to the freeway.

The best known is the **narrow diamond**. This has the crossing road ramp terminals close to the structure in an effort to keep the territorial requirements to a minimum.

Interchange Layout

The **wide diamond** is almost not on our design menu any more. The crossing road terminals are located roughly at the end of the approach fills to the structure, and sight distance is not a problem. Unfortunately, a lot of land is required for the road reserve.

The **split diamond** arises when the crossing road is actually a one-way pair of streets. The result is two bridges across the freeway about a city block apart. The ramps lie outside the one-way pair and are linked by street sections between the one-way pair.

Interchange Layout

A significant innovation is what may be termed the **double cross over diamond,** or the "**koeksuster" diamond**. We have already made scathing remarks about transposing the carriageways of freeways at a systems interchange, but this technique can be very effective when applied to the cross-road at a diamond interchange.

It is of value only where there are very heavy right turn movements from the cross-road onto the freeway. If the cross-road carriageways are transposed outside the interchange, then the heavy right-turn movement becomes a turn unopposed by oncoming traffic. The phasing and timing of signals becomes easier and capacity is increased.

Interchange Layout

A fairly new development is the **Single Point Diamond Interchange**, sometimes referred to as the Urban Interchange. (a poor name because any interchange in the urban area could be called an urban Interchange). The big trick about this interchange is that the crossing road ramp terminals are curved inwards to form a single four-legged intersection immediately above or below the structure.

Operationally, this is very efficient and the capacity of the SPDI is higher than that of the conventional diamond, although if the intersection is below the structure, it would be difficult to fit among bridge piers and the like.

Interchange Layout

The **Par-Clo** derives its name from the fact that it is based on the Cloverleaf but only in part. Hence Partial Cloverleaf and the abbreviation Par-Clo. In its operation, it resembles a distorted diamond, with simple ramps having stop-terminals at the cross-road.

There are two particular reasons for using a Par-Clo type interchange. **Firstly**, it allows an access interchange to be provided when one or two of the quadrants may be unavailable, and a conventional diamond can therefore not be built.

Interchange Layout

Secondly, the Par-Clo is very effective in dealing with heavy movements of traffic leaving the freeway to turn right onto the cross-road. A diamond ramp has its capacity constrained by whatever control is applied to its crossing road terminal. High volumes of right turners can become a problem, and if the length of the ramp is insufficient to supply storage space for all the vehicles that want to turn right, you end up with some poor soul being brought to a complete standstill on the freeway

Providing a loop for this movement makes it possible to convert the right turn into a left turn that can then flow continuously, assuming that a lane has been built on the crossing road to accommodate this.

Interchange Layout

The **Cloverleaf** has certain shortcomings in its large requirement for space and also the weaving movements it generates.

It might be possible to reduce the spatial demand by tightening up the loop radii but this soon becomes self-defeating. Tighter loops become operationally inefficient, and the travel time around a small loop is not less than around a large loop because of reduced speed. Even if you do put in a very small loop, the land area required will be determined by the radius and design speed of the adjacent outer connector ramp.

Interchange Layout

The **Directional Interchange** is purely a "systems" interchange. The directional ramp is the basis of a directional interchange. A "fully directional" interchange has all movements provided with directional ramps. A "partially directional" interchange has one or more loops for certain movements, in addition to directional ramps for all the other movements. In both cases, all the ramp terminals are high-speed tapers.

The Directional Interchange can climb to great heights both of complexity and altitude. The latter would typically arise in the case where all the right turn ramps and the intersecting roads cross at one point.

Interchange Layout

An alternative layout for the Directional Interchange uses more space by moving the crossing point of the ramps away from where the freeways intersect. This layout reduces the number of levels from four to three, but does so at the cost of several bridges and may not always have great merit.

The British Island-in-the sky layout is another totally different possibility, which also involves an amount of weaving. The major freeway is at ground level and the crossing freeway is two levels up while the ramps all converge on an island on the level in between. The island is, in effect, a rotary intersection.

Interchange Layout

The **Trumpet Interchange**, on the other hand is three-legged and its name derives from the overall shape of the interchange.

The trumpet has been used both as an access and as a systems interchange but its application these days is limited to systems interchanges. The previous application as an access interchange stemmed from cases of a freeway bypassing a town, with the town requiring freeway access from one side only. As we engineers subsequently discovered, if you attempt to bypass a development somebody is sure to start developing a township on the other side of the freeway.

Conclusion

Although the various interchange layouts have been discussed in some detail, the really important feature of interchange design is that the expectations of drivers should not be violated and that the series of decisions that they have to take in traversing the interchange area should be as simple as possible. The configuration of ramps that can best accommodate these principles is always the best layout to have.

The topography should not be seen as an enemy to be tamed but rather as having best-friend status. A convenient hillside can make it possible for a ramp to gain height over a crossing road without actually leaving ground level.