A COMPARISON OF INTERCHANGE PLANNING, OPERATIONS, AND DESIGN IN POLAND AND THE USA

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INTRODUCTION

This paper will endeavor to give an overview comparison of interchange (and freeway) planning and design in Poland and the USA. First, a presentation of the Polish freeway and interchange development program is presented. This is followed by the planning, operation and design guidelines. Finally, a comparison with USA guidelines is presented with recommendations.

Polish Freeway Program

The total length of the planned network of freeways and expressways in Poland is about 6100 km and consists of five tolled freeways of 2600 km and several sections of expressways with a total length of 3500 km. According to the freeway construction program approved by the Polish government, during the next 15 years, 4 tolled freeways with a total length of 2300 km will be built. Consequently 150-200 km of new freeways will be built annually.

The network will include 11 freeway/freeway, 13 freeway/expressway and 14 expressway/expressway interchanges, for a total of 38 system interchanges and about 70 service interchanges. The final number of service interchanges depends on a choice of layout variations on freeway segments in some urban and suburban areas and on the type of tolling system, which as yet has not been determined.

Legal Basis of Guidelines

The Polish *Design Guidelines for the 1st and 2nd Class Roads* (*1*) are the basis of geometric design for all new freeway and expressway construction and improvements. The design of interchanges is included in these guidelines. The guidelines are not mandatory national standards. Three types of designations are used, however, which do determine the level of mandatory obligation:

- Obligatory (should, should not, ought, ought not) - related mainly to traffic safety aspects,
- Recommended - related mainly to economical, operational, environmental and aesthetic aspects of design,
- Permissible - allowing departures from a recommended range of parameters in difficult design conditions; departures are individually described and are related to the use of existing road infrastructure and to the protection of road surroundings.

Four terms are also used in the guidelines: minimum or maximum and minimum recommended or maximum recommended. The minimum value means that a lower value of a parameter should not be accepted, whereas the recommended minimum means that a higher value should be applied if it does not bring too high an increase in cost. Departures from the guidelines usually require specific approval.

The guidelines aspire to provide a coherent design philosophy and a well engineered road design, taking into account safety, economics of construction, vehicle usage, and environmental concerns. The concept of design speed is fundamental to the geometric design of freeways and expressways and their interchanges. In the new guidelines speeds higher than the design speed, i.e. vehicle operating speed V_{85}, are used for determination of those parameters which, for the reasons of traffic safety, should be adjusted to conform with unconstrained vehicle speeds.

Since the beginning of the 1990's, work has been undertaken to develop a set of design guidelines for Polish roads. In a new guideline for design of freeways, which has been recently completed, Polish and Western European experiences were included. Therefore in this paper design considerations will be related to the new guidelines, whereas statistics are based on data from the existing road network and previous planning, operational and design guidelines.

Specificity of Polish Interchanges

Construction of interchanges on a large scale began in Poland in the 1970's mainly in urban areas. Lack of experience forced the road administration to use foreign configurations in the Polish guidelines, linking some American and Western European experiences from the 1960's. The first interchange design guidelines included only the most important design considerations. In design practice, economy was the primary determinant.

In the past, interchanges in rural areas generally met the requirements of that time. With respect to the present state of knowledge, those interchanges show several deficiencies, namely:

- Restricted visibility distances - particularly decision sight distance and as a result, insufficient perception of the exits from the freeway and from ramps,
- Insufficient spacing of ramps, resulting in poor informational signing of exits,

- Short deceleration and acceleration lanes; fixed values of 150-200 m were used, which in typical conditions are usually too short (see Table 3 and 4),
- Short tapered exits and entrances on the freeway and on ramps, and
- Weaving allowed on the main carriageway of the freeway (for example: weaving on a cloverleaf without collector distributor roads).

Interchanges on urban expressways and freeways reveal the same deficiencies. Moreover, on the urban expressways left side exits from the mainline and from ramps, provided for relatively small traffic streams, can be found. Today this is not permitted.

INTERCHANGE FORMS AND OPERATIONAL CHARACTERISTICS OF INTERCHANGES

Depending on the classification of the crossing roads and type of traffic control, Polish guidelines classify interchanges into three groups:

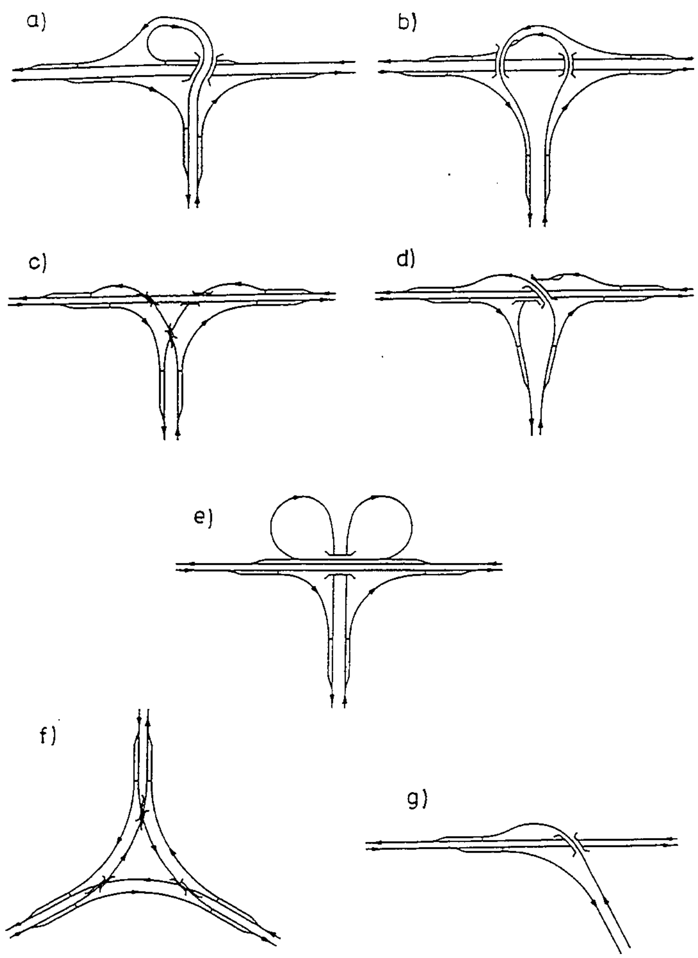


FIGURE 1 Three-Leg Interchanges

a) System Interchanges (named WA - Figure 1 and 2), which are located at freeway/expressway (freeway) network nodes and where drivers negotiate with merging, diverging and weaving maneuvers and crossing conflicts do not exit.
b) Service Interchanges (WB - Figure 3), which are located along freeway and expressway segments, providing access to adjoining highways and streets of lower classes. Thus, at the service interchanges, the main freeway traffic streams are free flow and grade separated (drivers negotiate with merging, diverging, and weaving). Most maneuvers on the lower class roadway are through at-grade intersections.
c) Other Interchanges (WC), at which only the major traffic streams are grade separated. This type (quarter cloverleaf) is not used in the network of freeways and motorways, but between two lower class highways.

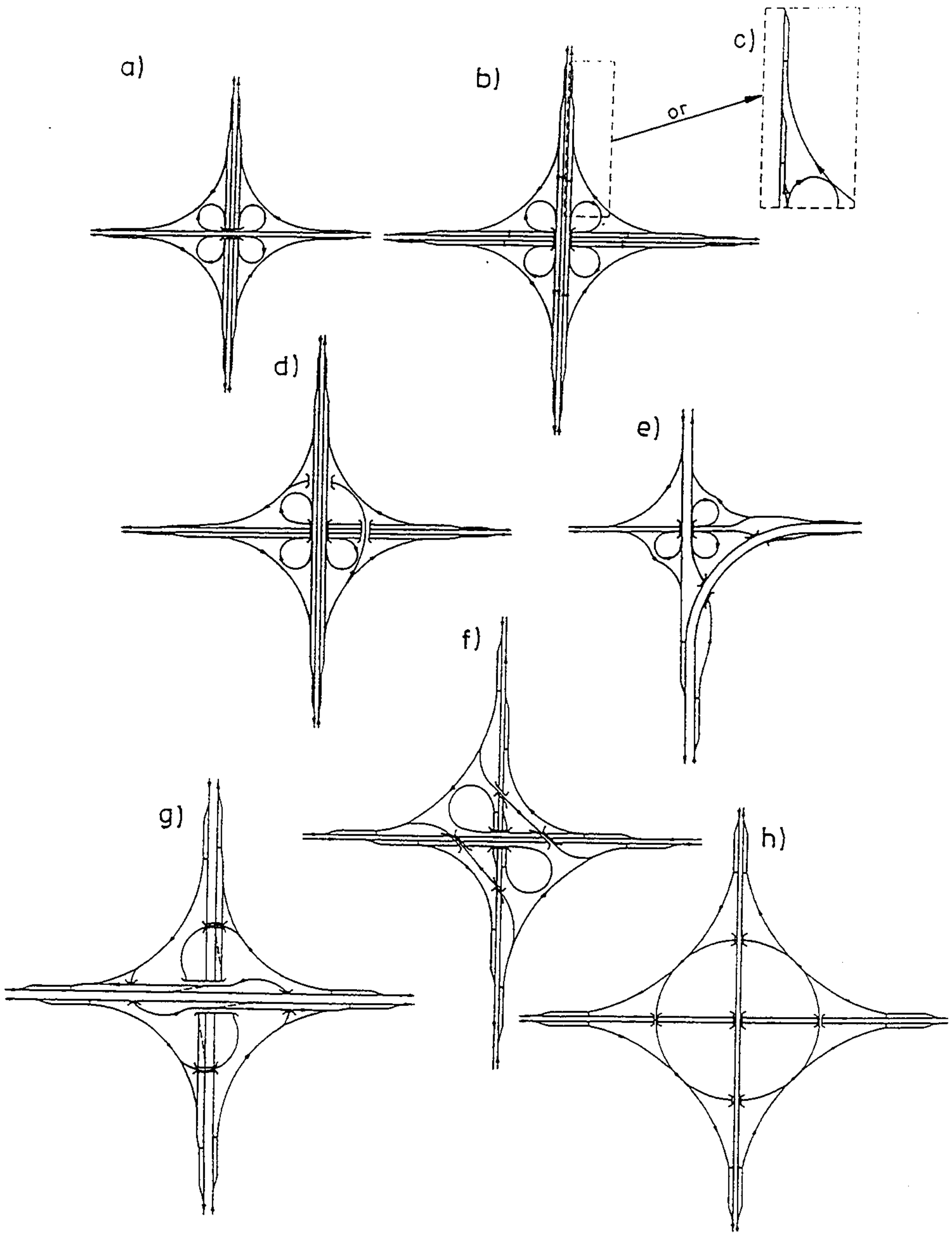


FIGURE 2 Four-Leg Interchanges

Further guidelines depend on the function and type of highway intersecting the freeway or expressway and on the character of the area in which the interchange is situated (urban or rural). Only the system interchanges can be located on the freeway/freeway and freeway/expressway nodes. The service interchanges generally are located along freeways and expressways interchanging with lower class roadways, but they occasionally may be located at expressway network nodes as with an at-grade expressway.

Individual choice of the interchange form is allowed, in spite of the guidelines of typical designs for three- and four-leg interchanges. Selection of a specific geometric form of interchange is from one of two groups and should be based on general recommendations. In the selection process road safety, operational efficiency and economics are considered. The selected form of interchange should provide:

- Minimum land acquisition,
- Possibility of construction staging, depending on traffic demands, and
- Minimum environmental impacts and consideration of aesthetics.

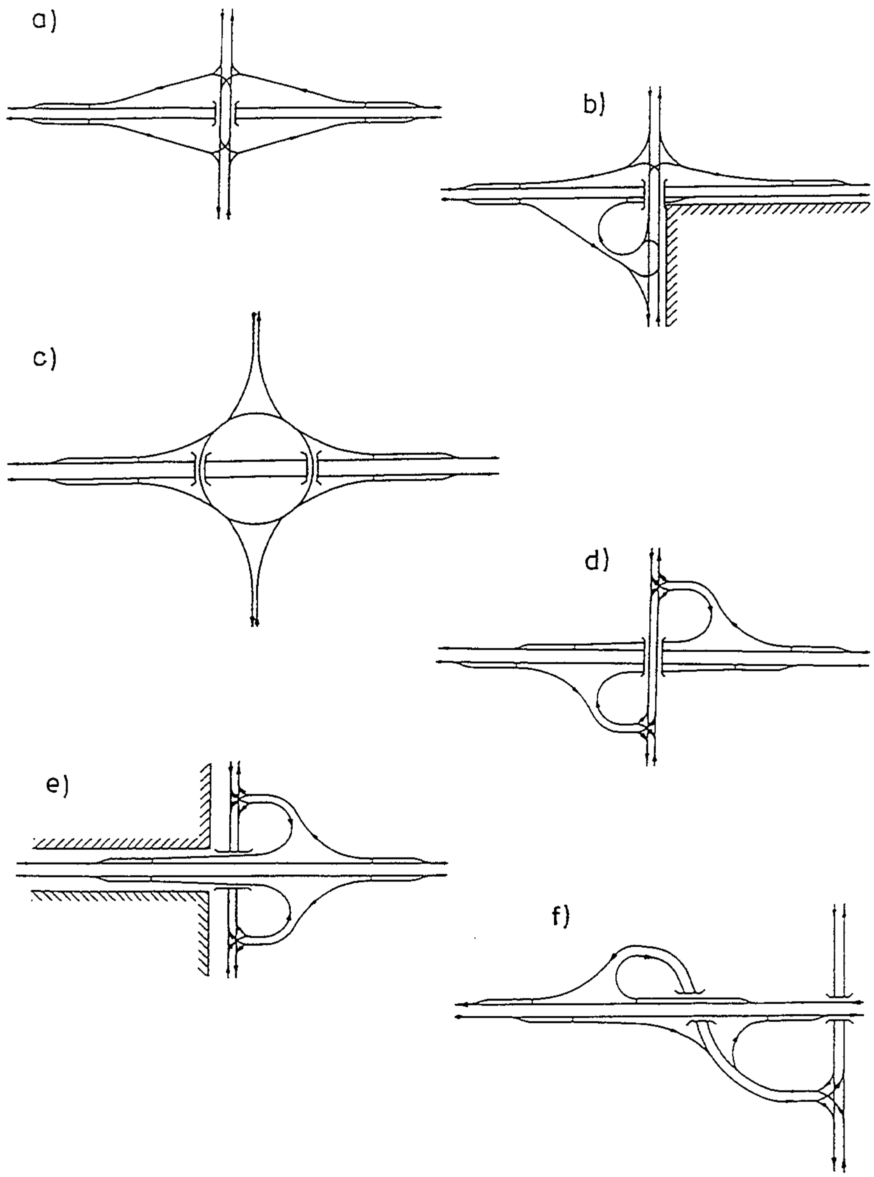


FIGURE 3 Service Interchanges

Traffic safety at an interchange depends on:

- Recognition of its points of diverging and merging and provision of adequate spacing between them,
- Limitation of the number of exits and entrances on the mainline and clarity of interchange elements, and
- Comprehension of interchange elements and related signing.

The more detailed requirements (*1*) are formulated as follows:

- Exit should be situated in advance of entrance,
- Only right side, single exits and entrances for interchanges should be planned; on exception left side exits from one-lane ramps may be planned when linked with adding of one lane,
- Weaving should not be situated on the mainline within the interchange,

- Road carrying lower traffic volume should enter road carrying higher traffic volume from the right side,
- Carriageway of the higher class road should have a good alignment and preferably pass under the crossing lower class road, and
- The planned layout should have the proper directional signing and route marking for the driver approaching the point of bifurcation to allow the driver to be positioned properly across the lanes.

Suitability of the interchange form determined at each location and its relationship to preceding or following interchanges has become imperative to a balanced design providing traffic safety on freeways.

Adaptability of interchange forms using a two-step expert system is commonly utilized in Polish practice. The group of interchanges presented here form the basic set for a selection of an interchange, taking into account the general site conditions. The two-step expert method is a useful tool in the selection process. Unfortunately, until recently the selection of the typical interchange form is done without analysis of optimal adaptability. To sum up the requirements, it can be stated that the selection of a form of interchange is mainly determined by:

- Set of typical interchanges included in the guideline (*1*) and in other references (*2,3,5*),
- Topography,
- Classification of the intersecting roads, and
- Urban vs. rural environment.

Analysis of the past and current Polish designing practice shows that the majority of interchanges are cloverleaf interchanges (30%) and partial cloverleaf interchanges (40%). There are also some diamonds, trumpets, and other 3-leg forms. In general, there are very few designs that are essentially different from the recommended typical forms. Analysis of the urban expressways shows frequent selection of the diamond type interchanges and their modification (~30%), partial cloverleaf interchanges (20%) and cloverleaf interchanges (15%). In the urban environment, more frequent are non-typical, individual forms of interchanges, in which the typical forms were significantly modified. In urban areas, interchanges without provision of some movements can be found. That is not the case in rural areas.

The planned implementation of tolling on Polish freeways can significantly change the existing plans or even completed construction limiting the choice of interchange forms. In the case of a tolling station interchange combination, the new guidelines recommend trumpet and semidirect trumpets as shown in Figure 4.

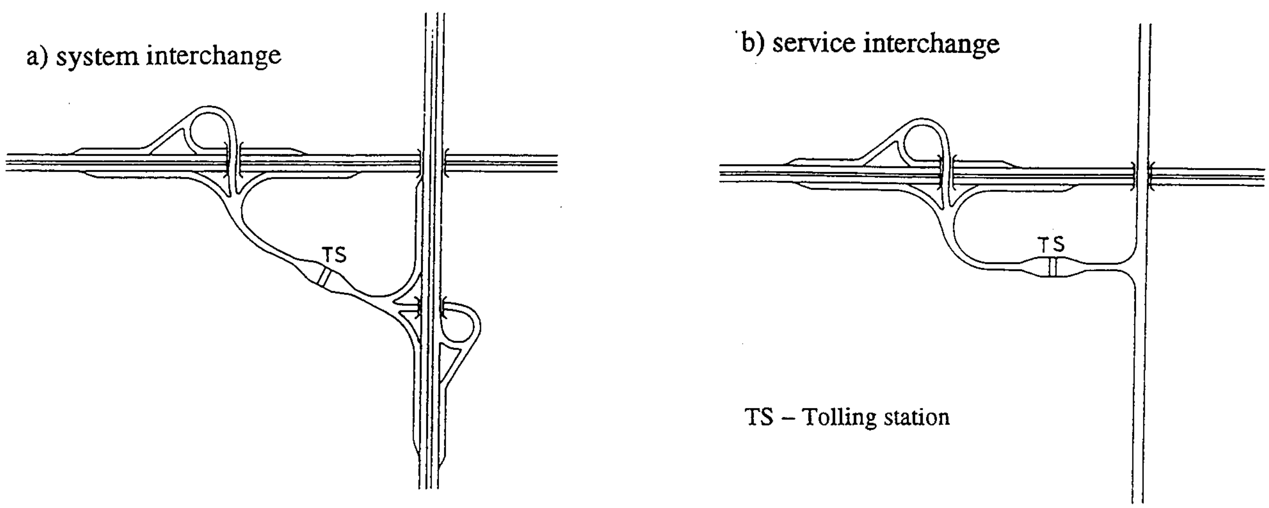


FIGURE 4 Types of Interchanges with Tolling Station

OPERATIONAL GUIDELINES FOR A SYSTEM OF INTERCHANGES

Operational considerations deal mostly with communicative aspects between the driver and the freeway/interchange complex in which the intent is to clarify, simplify, regulate and facilitate driver operations. These Polish operational guidelines are as follows:

- Route continuity,
- Right side exits and entrances,
- Operational uniformity,
- Lane balance at exits and entrances,
- Adequate spacing of interchanges and ramps, and
- Signing feasibility.

Route Continuity

Route continuity refers to the provision of a directional path throughout the length of a designed route. It is realized through suitable geometric design and directional signing. The designation pertains to a route/freeway number and sometimes to the name of a city. Route continuity allows the driver approaching an interchange to be positioned properly across the lanes, followed by a confirmation received from directional signing and route marking.

In the process of keeping the driver "on-line", particularly within and bypassing urban areas, interchange configuration must not necessarily favor the heavier traffic movement at the point of bifurcation. It is the through facility (the designated route) that should always maintain its directional character. However, any predominant movement separating from the freeway should form a well aligned exit on the right, equivalent operationally to the through movement. Important is that the driver, to remain on route, stays to the left and to leave or exit the route moves to the right and exits right.

In Poland, the continuity requirements are limited to clear directional signing coherent with general European rules. Designing directional or semidirectional ramps provides advantageous conditions for the predominant turning movements. Examples of such forms of interchanges are shown in Figure 2 (d,e).

Right Side Exits and Entrances

Operational experience and accident analysis gained in European countries and in Poland have shown conclusively that only right exits and entrances for interchanges should be used. Left side exits create several operational and safety problems. The exception to this guideline may be at major forks in urban areas.

Interchange Operational Uniformity - Single Exit in Advance of Cross Road

In general operational uniformity is not directly included in the Polish guidelines (*1*). There is no recommendation of usage of repeatable forms along freeway segments. However, the recommendation of repeatability is focused on elements of interchanges, which have an impact on decision making by drivers. It is related mainly to exits and entrances, weaving sections and intersections at the service interchanges.

The single exit recommendation is included in the new Polish guidelines in order to simplify driver's decisions by providing only one decision point on the freeway. The guideline related to a good view of the exit ramp in advance of the cross road has not, as of yet, been considered. This gap particularly results in operational <u>non</u>-uniformity and especially affects forms of partial cloverleaf interchanges frequently used in Poland as service interchanges. Those partial cloverleaf forms do not provide exits in advance of crossroad. With relatively simple geometric adjustments each interchange of this type can have a single right exit in advance of crossroad. This uniform pattern of exits also produces a uniformity of signing along the freeway, further simplifying the driver's decisions.

The cloverleaf previously used as the form of interchanging two freeways was constructed with four short weaving sections on the main line between loops, resulting in weaving and accidents. It is now recommended to use the cloverleaf with single exits leading to collector distributor (C-D) roads, with one or two entrances from these C-D roads. This type of cloverleaf provides a single exit in advance of crossroad, thus maintaining operational uniformity and reducing accidents.

Lane Balance at Exits and Entrances

In the Polish guidelines only 2- and 3-lane freeway cross sections are considered. Therefore, problems of lane balance are less important than in Western European countries. Generally, at the present level of traffic volumes, considerations related to staging of cross section construction and its impact on the operational efficiency and possible traffic disturbances is perhaps more important.

Capacity analyses, conducted in Poland on the basis of the adopted Highway Capacity Manual (HCM) (6) procedures, sometimes indicate abrupt changes in number of lanes at points of entrance or exit. Whereas such changes may be logical in terms of volume-capacity relations, they are not always appropriate in achieving smooth operating characteristics. Therefore it is pointed out in the guidelines

(*1*), that smooth traffic operation requires maintaining of a certain balance of lanes. In general it is recommended to comply with lane balance as is described in (*2, 5*). At exits the number of lanes approaching should be equal to one lane less than the combined number of departing lanes. At entrances the combined number of lanes after the merge should either be equal to or one lane less than the total number of lanes approaching the merge.

Lane balance could produce a lane drop at certain exits. This need not be so as long as the lane dropped is an auxiliary lane added to the freeway at a previous entrance ramp. Thus the basic lanes or established through lanes are maintained over the length of the freeway facility. These guidelines of lane balance, basic lanes, and application of auxiliary lanes to accommodate entering, exiting and weaving traffic between interchanges were adopted in the Polish Guidelines as an important element in reducing lane changing and achieving uniform operation. Many traffic jams on Western European freeways are created by an abrupt reduction of the number of lanes.

The Polish guidelines recommend the spacing of service interchanges at least 2.0 km apart and in rural areas 2.5 km apart. The system interchanges should be spaced at least 2.7 km apart. This spacing generally provides for sufficient weaving distances between interchanges. It also allows for sufficient spacing of guide signs providing information for exits at the interchanges.

Guidelines have been developed for spacing of exits and entrances within and between interchanges. This spacing, presented in Table 1, relates to geometry and operation of merging, diverging and weaving elements. These distances are only guidelines and may need to be modified by actual traffic and geometric conditions of a specific freeway or expressway.

DESIGN CONSIDERATIONS

The design elements of an interchange include the ramp exits and entrances, the ramp proper and in the case of a service interchange the at-grade intersection where the ramp(s) intersects with the cross road. This paper only highlights some (perhaps the most important) design elements of an interchange that affect efficient and safe operation as experienced in West European countries and in Poland. To be discussed here are the following:

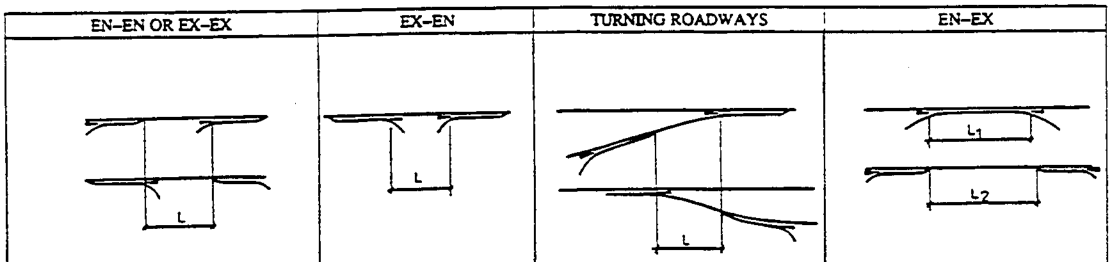
- Ramp Alignment and Grades,
- Ramp Cross Section,
- Exit/Entrance Geometrics,
- Geometric/Design Speed Relationship Between Freeway and Exit Ramp, and
- Decision Sight Distance.

Ramp Alignment and Grades

The horizontal alignment of ramps in interchanges differs between service and system interchanges and between ramp type, right turning vs directional vs loop. The design speed V_d for a ramp is selected depending on the type of ramp and the form of interchange (Table 2). For a loop ramp it can be seen that the V_d value depends also on the geometry of the loop or fitting the loop to an available area. On ramps, clothoids are used for transitions with a parameter ranging from 1/3R R. On service interchanges transition curves (mainly clothoids) are used to link the ramp with the mainline.

Grades on ramps are usually kept as flat as possible and depend on the ramp design speed; for exit ramps 4-6% grades, for entrances on uphill 3-6% and for downhill 4-7% grades are considered maximum.

TABLE 1 Recommended Minimum Ramp Terminal Spacing

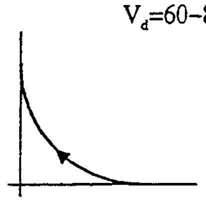
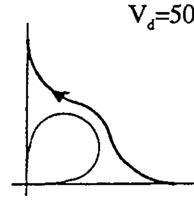
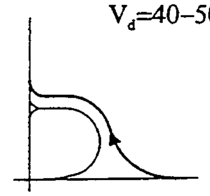
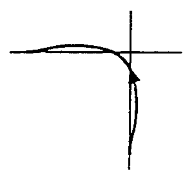
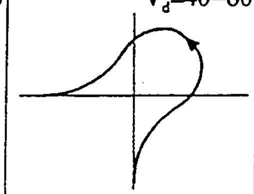
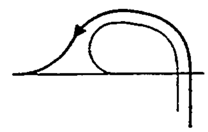
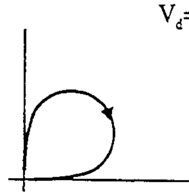
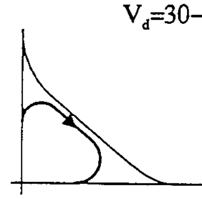
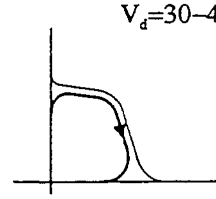


EN–EN OR EX–EX		EX–EN	TURNING ROADWAYS		EN–EX	
FREEWAY	CDR	FREEWAY OR CDR	SYSTEM INTERCHANGE	SERVICE INTERCHANGE	FREEWAY	CDR
MINIMUM LENGTHS........						
EX–EX 200–300[1] EN–EN 200	EX–EX 100–200[1] EN–EN 150	NOT INCLUDED	200–300[1]	150–200[1]	L_1=300 L_1=600	L_1=230

[1] Dependent on V_d

NOTE: CDR – COLLECTOR DISTRIBUTOR ROAD
EN – ENTRANCE
EX – EXIT

TABLE 2 Types of Ramps and Recommended Design Speeds (km/h)

Type of ramp	Ramps in system interchanges		Ramps in service interchanges
	Free design	Tight fitted	
Directional (right turning)	V_d=60–80 	V_d=50–60 	V_d=40–50 
Semidirectional	V_d=50–70 	V_d=40–60 	V_d=40–50 
Loop	V_d=40 	V_d=30–40 	V_d=30–40 
Directional	Collector distributor road V_d = 60– 80		V_d=40–60

Ramp Cross Section

Generally, ramps are one or two lanes in the Polish guidelines with shoulders on both sides. The typical one-lane ramp is 4.5 m in width and the two-lane ramp 7.0 m in width. The right shoulder varies from 2.0 m to 3.5 m (including 0.5-1.0 m of paved shoulder), while the left shoulder varies from 1.5 m to 2.0 m (including 0.5 m of paved edge strip).

Exit and Entrance Geometrics

The Polish guidelines recommend a parallel entrance design only, whereas on exits also tapered design is allowed. The parallel exit design is also used for exits from ramps or collector distributor roads with a parallel lane of 100-150 m length.

Examples of typical one-lane and two-lane parallel and one-lane tapered exit designs are shown in Figure 5. The length of exit section depends on the difference of freeway speed and speed on the ramp curve. In such cases, instead of design speed, operating V_{85} speeds is considered, as it better describes the real behavior of drivers.

The length of the deceleration section L_d (Table 3) is calculated at the deceleration rate of $1.5\ m/s^2$, taking also into account the difference of speeds ΔV and the grade on the exit. Additionally verified is the length L_o of the parallel lane, which should be minimum of 150-200 m depending on the freeway operating speed V_{85}. The length L_d is calculated at the deceleration rate of $3.5\ m/s^2$ in order to allow safe maneuvering of late-diverging vehicles (at the end of deceleration lane). Distance L_o is used in order to allow lane changing by drivers who start their diverging maneuver very late. This can be caused by delayed driver decision or dense traffic.

TABLE 3 Length of Deceleration Lanes L_d

Δ V (km/h)	Length of deceleration lane L_d (m)							
	-5	-4	-3	-2	0	+2	+3	+4
60	280	250	230	210	190	170	160	150
50	250	230	210	190	170	150	140	130
40	220	200	180	170	150	130	120	110
30	170	160	150	140	120	110	100	90
<20	120	110	100	95	85	75	70	65

$\Delta V = 0.75\, V_{85} - V_d$

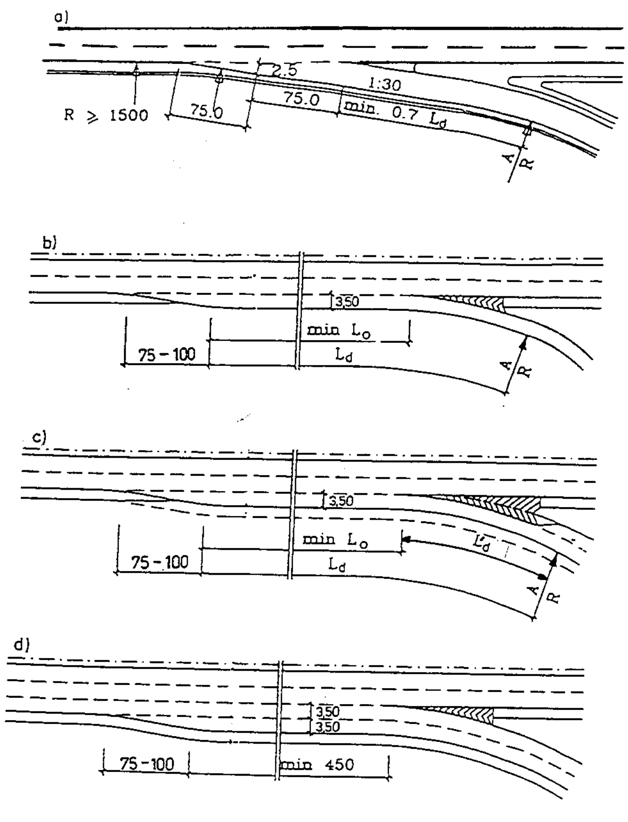


FIGURE 5 Deceleration Lanes

Examples of parallel entrance designs are shown in Figure 6. The length of merging depends on the difference of speeds on the mainline and on a ramp and on the entrance grade. Lengths of the acceleration lane (L_a) are taken from Table 4. In calculations of the acceleration lanes, different values of acceleration rates, depending on the limited speed of the merging vehicle, were used. Additionally verified is the length L_o of the parallel lane, which should be a minimum of 150 -250 m depending on the freeway operating speed (V_{85}).

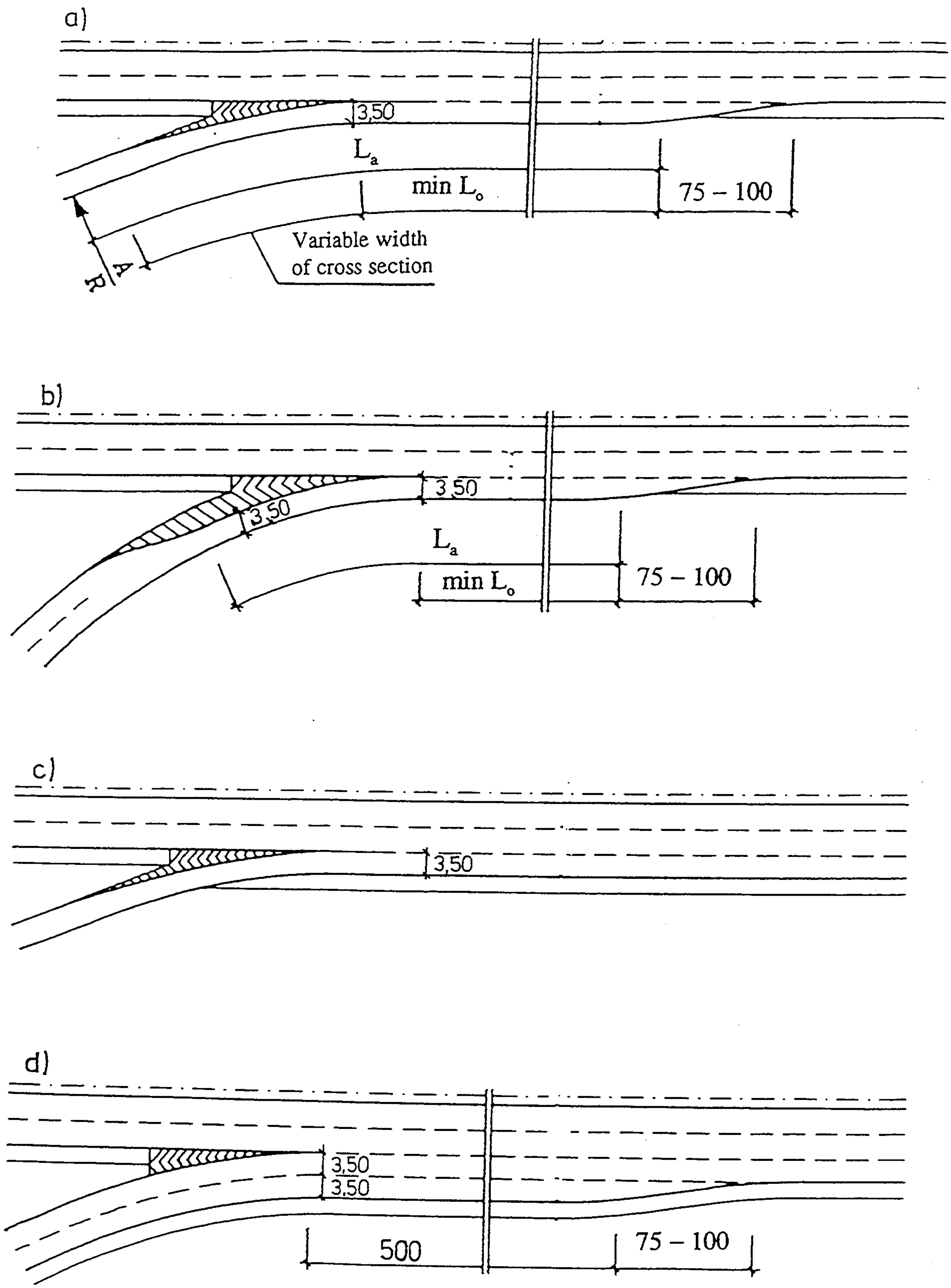


FIGURE 6 Acceleration Lanes

TABLE 4 Length of Acceleration Lanes L_a

ΔV (km/h)	Length of acceleration lane L_a, (m)							
	-5	-4	-3	-2	0	+2	+3	+4
60	190	200	210	230	270	340	390	450
50	170	180	200	210	250	320	370	430
40	150	160	180	190	230	290	330	400
30	130	140	150	160	200	250	290	350
<20	90	100	110	120	160	200	240	300

$\Delta V = 0.75\ V_{85} - V_d$

Geometric/Design Speed Relationship Between Freeway and Exit Ramp

This criterion refers to the deceleration distance required for the driver to decelerate the vehicle from the speed of the freeway to the speed of the controlling curve of the ramp. The dimensions indicated are from the beginning of deceleration lane of the exit ramp to the beginning of the controlling curve of the ramp. The assumption is that the vehicle is traveling at approximately the freeway speed on the deceleration lane and decelerates at a comfortable rate to the ramp curve. In order to decrease the operating speed V_d (Figure 7), successively decreasing the exit curve radii is recommended. The ramp curve is preceded by the transition curve (with parameter A), beginning at the end of parallel lane, usually at the physical gore. The purpose of providing the distance L_d is not only for safe vehicle deceleration and operation but also to eliminate the need for drivers to decelerate on the freeway, thus providing safer operation.

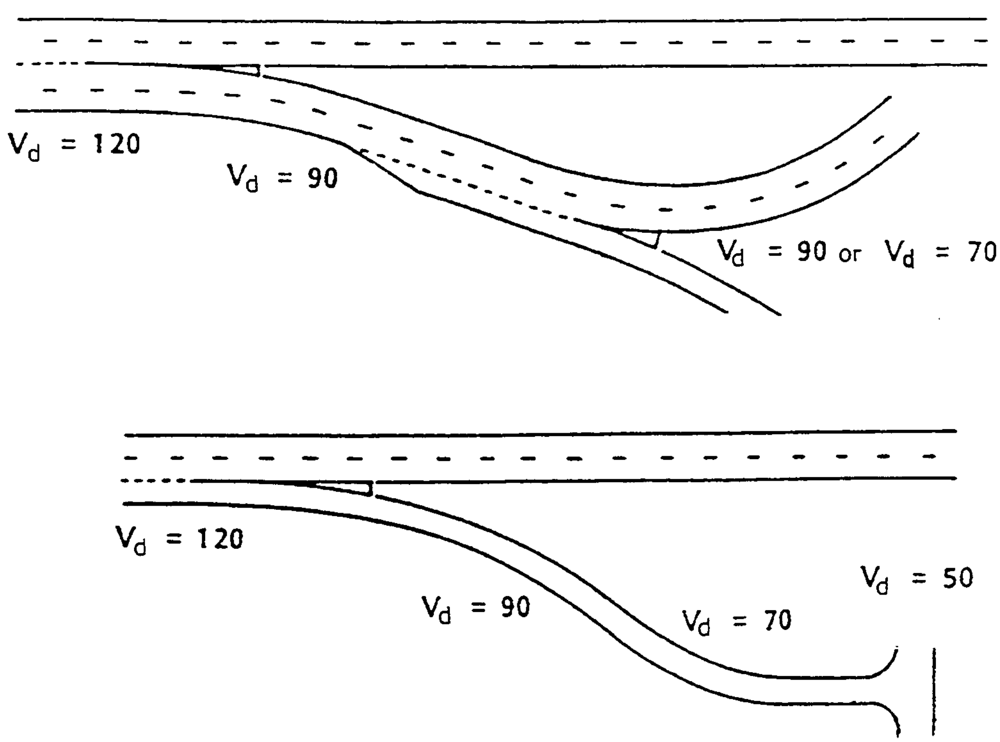


FIGURE 7 Gradually Decreased Design Speed

Decision Sight Distance

Decision Sight Distance criterion, which relates to the distance at which a driver can perceive a decision point along the freeway, is not used in Polish practice and again has not been included in the new Polish guidelines. It seems to be a very reasonable criterion and should be included in the design practice in the future. Two other criteria are used in the design practice; the stopping sight distance and checking of the visibility triangle in a merging area (Figure 8).

CONCLUDING REMARKS

The new Polish guidelines meet the needs of rapidly growing traffic, and the program of the motor way network development. Experiences collected for years, related mainly to operational aspects and road safety, are linked with:

Environmental impacts,

- Movement of traffic flows, not only individual vehicles,
- Traffic control and surveillance,
- Road tolling, and
- Need for unification with European standards, due to the increase in international traffic.

The main changes in design of interchanges include:

- Exit and entrance zones with preference to parallel acceleration and deceleration lanes and lengths resulting from dynamics of vehicles in traffic flow,
- Removing weaving from the mainline with lengths derived from capacity calculations, and
- Noticeable impact of signing and traffic guidance on geometric design of interchange elements.

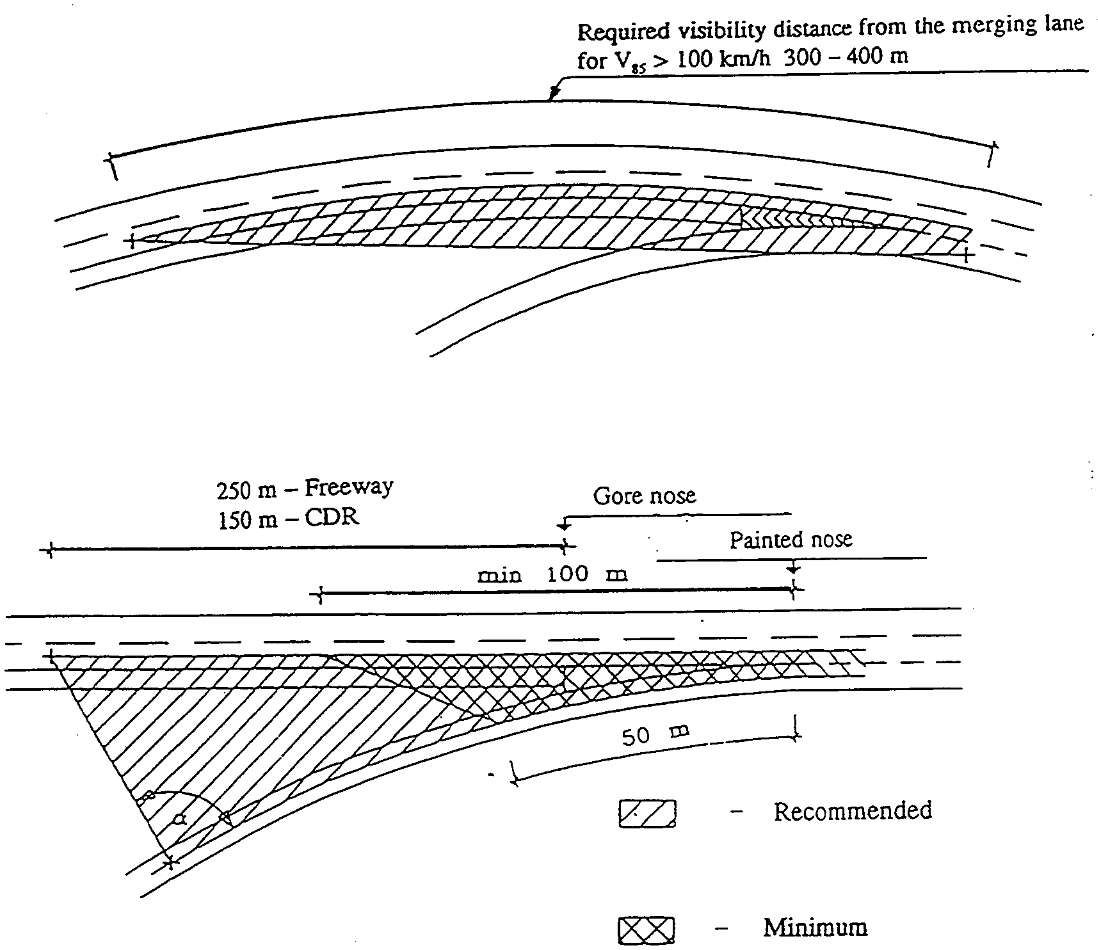


FIGURE 8 Checking of the Visibility Triangle in a Merging Area

The new Polish guidelines recommend similar solutions of basic interchange elements to Western European and American guidelines. Some differences resulting from economic constraints and requirements of express roads can be found. An adopted tolling system can have further impact on limitation of a number of interchange types. It can also force modernization of existing interchanges to non-typical forms, which are not included in recommended sets. Poor traffic conditions and dangerous behavior of drivers, when negotiating interchanges constructed in the 1960's and 1970's, requires modernization according to new guidelines, particularly in exit and entrance areas, at busy interchanges.

Past experience has shown that application of the HCM (*6*) procedures for calculation of capacity and traffic conditions at exit, entrance and weaving areas - particularly those closely spaced in urban areas, with high traffic density - may not be appropriate in Poland. In recent years consideration of environmental aspects often dominate over road safety and operational aspects of interchange design.

COMPARISON WITH U.S. INTERCHANGE PLANNING, OPERATIONS AND DESIGN

Experience with freeway and interchange design and operation has a long history in the United States. The first interchange (a cloverleaf) was constructed and opened to traffic in Woodbridge, New Jersey, in 1928. By 1975 more than 65,000 km and nearly 12,000 interchanges were constructed. During that period (nearly 50 years) design criteria and operational guidelines changed significantly based on extensive human factors research, accident experience and field observation. Many mistakes (most unknowingly) were made during this evolving period as a result of inexperience. Today, however, the AASHTO "*Policy on Geometric Design of Highways and Streets*" along with other publications by AASHTO and the Transportation Research Board incorporate the latest criteria and guidelines based on (now) nearly 70 years of experience.

Because much of the U.S. freeway/interchange system was constructed prior to 1975, there is a significant need to reconstruct and rehabilitate, not only to increase capacity but to update design criteria and operational guidelines to improve operational efficiency and further reduce accident experience.

The United States is probably 30 years ahead of Poland in development of its freeway and interchange system. Even though Poland has recently adopted some of the criteria and guidelines from the United States and Europe there are still some significant differences which will be discussed here.

Interchange Forms

Basic forms of interchanges in the United States were adopted by the 1940's. These are similar to the Polish basic forms; however, variations of the basic forms differ somewhat. The most common form of interchange in the United States is the diamond (of which there are a number of variations). The cloverleaf is gradually becoming extinct because of its excessive right-of-way, operational deficiencies and high accident experience. These are often being converted to partial clover leafs with loops in opposite quadrants to eliminate weaving. System interchanges (freeway to freeway) have become greatly simplified, applying the concepts of single exit design and no weaving within the interchange developed from the research and vast experience in interchange operations. The result is two basic forms - directional and directional with 2 loops in opposite quadrants.

It appears that Poland is still "experimenting" with interchange forms. It is recommended that Poland reconsider its interchange forms to simplify and achieve operational uniformity. This would most likely reduce accident experience.

Operational Guidelines for Systems of Interchanges

Poland has adopted many of the United States guidelines for freeway and interchange system operations. Some, however, such as route continuity, are not being adopted in a similar way as in the United States. It is apparent that this guideline would be of significant benefit to operations on Polish freeways in particular as related to improving safety.

Decision sight distance has become an important element in freeway and interchange design in the United States. Based on the human factors research in the 1970's and accident experience, this criterion has become important in reducing accidents and improving operations. Poland should consider adopting this guideline.

Exit and Entrance Design

Generally, the United States utilizes tapered entrance and exit designs. Exit tapers are usually 1:10 - 1:20 and entrance designs are 1:50. These are lengthened or parallel lane designs are implemented based on profile and merging or diverging operating speeds. The United States at present does not use a criterion for sight distance at entrances as Poland. Consideration should be made for this by the United States.

Alignment Considerations

Generally, criteria for horizontal and vertical alinement of ramps are similar. There are, however, a few differences. It appears that Poland suggests some irregular ramp alignment - particularly loop ramps, while the United States in the past developed loop ramps with irregular geometry. In the past 20 years existing alignments have been modified or new designs developed that have more uniform alignment that produce lower accident rates and more consistent operation.

Poland, on the other hand, utilizes transition curves (clothoids/spirals) generally more extensively than in the United States. These are applied on ramps and at exits and entrances. The United States generally has gradually reduced the application of clothoid/spiral curves. This is unfortunate because these greatly facilitate superelevation development and facilitate driver operations as well as add to the aesthetic quality of the highway.

Summary and Conclusions

For decades the United States has been a leader in freeway and interchange design and operations. Extensive research has been conducted related to human factors, traffic operations and geometric design criteria. Poland, as well as many other countries, can and has benefitted from this research. On the other hand, the United States can benefit from the experiences in European countries in particular with respect to application of 85th percentile operating speed for design and implementation of clothoid/spiral transition curves.

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