Evaluation of Frontage Roads as an Urban Freeway Design Element

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This paper discusses the design and operational aspects of frontage roads and diamond interchanges and develops criteria for their use. Continuous frontage roads have been used extensively on urban freeways in Texas and much operational experience on freeways using these elements has been obtained. Freeway studies have indicated that numerous advantages in system flexibility, capacity, operation, and construction have been obtained with this type of facility and this paper discusses these advantages and presents supporting data obtained from freeway studies in Texas.

A capacity analysis is developed for conventional two-level, split two-level, and three-level diamond interchanges. The results of this analysis indicate the wide range of interchange capacity that can be obtained with these three variations. The capacity analysis also points out various design criteria necessary to obtain maximum operational efficiency and capacity.

•A FRONTAGE ROAD is defined as a local road auxiliary to and located on the side of an arterial highway for service to abutting property and adjacent areas and for control of access (1). Its function is to control access to the traveled way for through traffic where it cannot be controlled otherwise, to provide access to the property adjoining the highway, and to maintain circulation of traffic on the street system on each side of the arterial highway (2). An example of an urban freeway-frontage road system is shown in Figure 1.

From the preceding definition and statement of function, it is easy to see how the frontage road has acquired several commonly used names, such as frontage road, auxiliary road, service road, access road, and collector-distributor. Each of these names is related to a particular function of a frontage road and collectively they indicate the multifunctions of a frontage road. The term "frontage road" is a more common name for the facility discussed in this paper and for that reason, it is used throughout this report.

A frontage road serves a multitude of purposes that are probably not widely recognized. Often, the frontage road is thought of only as a means of providing frontage to abutting property for the control of access. However, the frontage road also adds tremendous flexibility to the operation of a freeway when used as an auxiliary facility.

This paper focuses attention on the frontage road as a design element of an urban highway network and presents data regarding the frontage road, its uses, and its benefits to urban transportation.

ECONOMIC CONSIDERATIONS

The manner in which access to a freeway is regulated is an extremely important factor and affects both the operation of the freeway and development of areas adjacent

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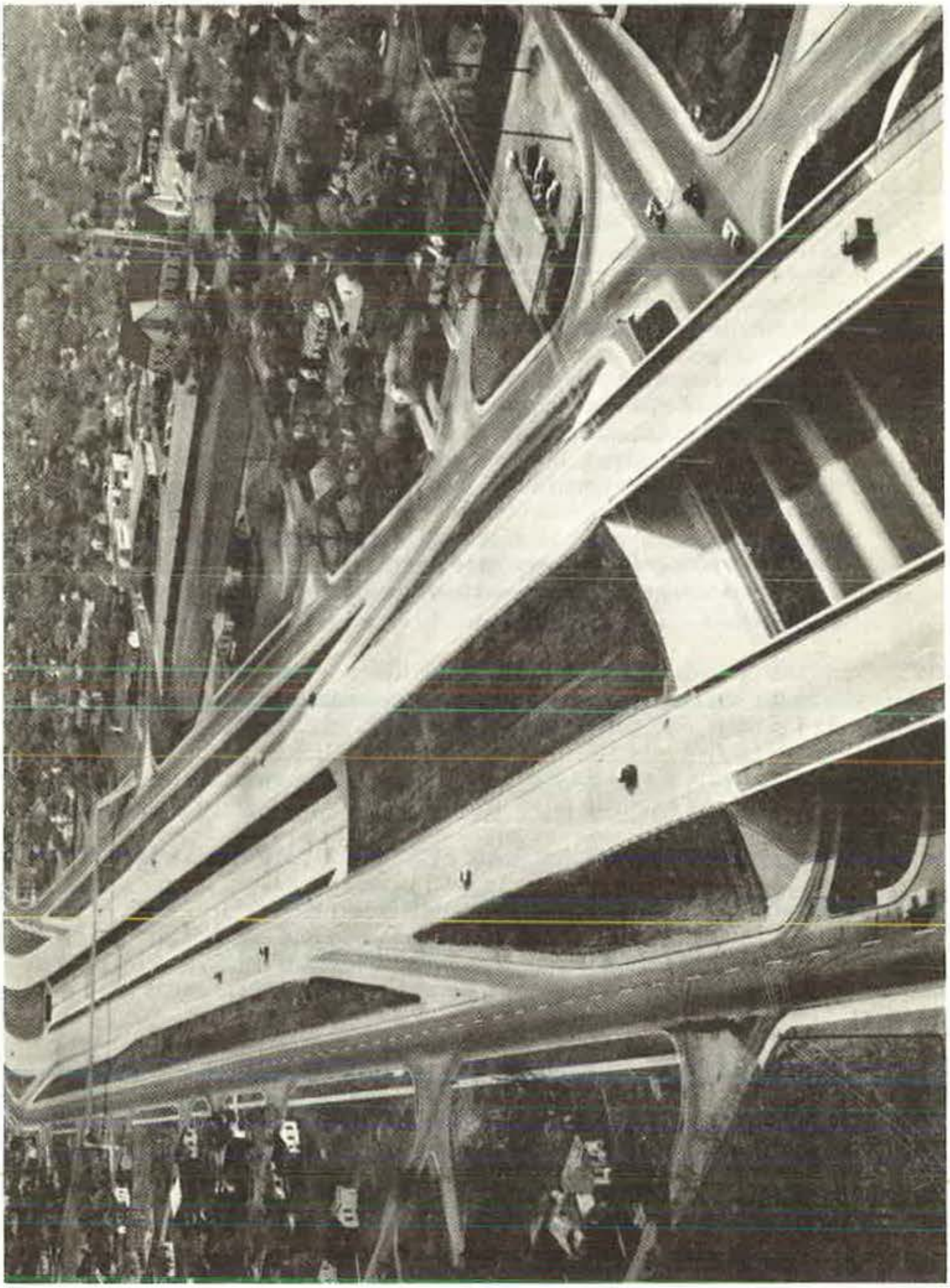


Figure 1. Urban freeway-frontage road system.

to it. The connections to the freeway proper have become fairly well standardized and are therefore not considered in this discussion. The arrangement of the off-freeway end of the ramp has been treated in a number of ways which can generally be categorized as frontage-road and non-frontage-road or closed-corridor designs. The relative economics of these two have been discussed at great length, but possibly some of the significant considerations have not been fully developed.

When the closed-corridor method of controlling access to a freeway is employed, it is necessary to secure either by purchase or by other means any right of access that the owner of any adjacent property may have to the freeway. It may also be necessary to compensate him if his property has been cut into two parts by the freeway. If, before building the freeway, access to his property has been gained by way of a road that is to be replaced by the freeway, it may be necessary to compensate him if he can no longer get to his property or to provide him an alternate access route. These things all cost money, and the value of some of these is often hard to determine accurately.

In theory when a freeway is put on a new location where no road existed previously, the adjacent landowners do not possess any right of access to the freeway. In dealing with these situations, however, the land often costs more than it should and part of this additional compensation is no doubt due to the fact that the landowner is not given access to the freeway.

Damages resulting from the construction of a freeway are extremely hard to determine accurately, and even in the case of a closed corridor, are actually apt to be negative or result in enhancement of value in the long run. Probably the most difficult feature of the entire problem, however, is to treat all property owners fairly.

For example, there is a 3-acre tract of land (Tract 1) located on a crossroad at a closed-corridor freeway interchange (Fig. 2). This property is accessible from the freeway due to the crossroad interchange and is subject to an almost immediate change in land use and to a considerably higher selling price. The fact that the side of this property adjacent to the freeway has an access control fence along if for its entire

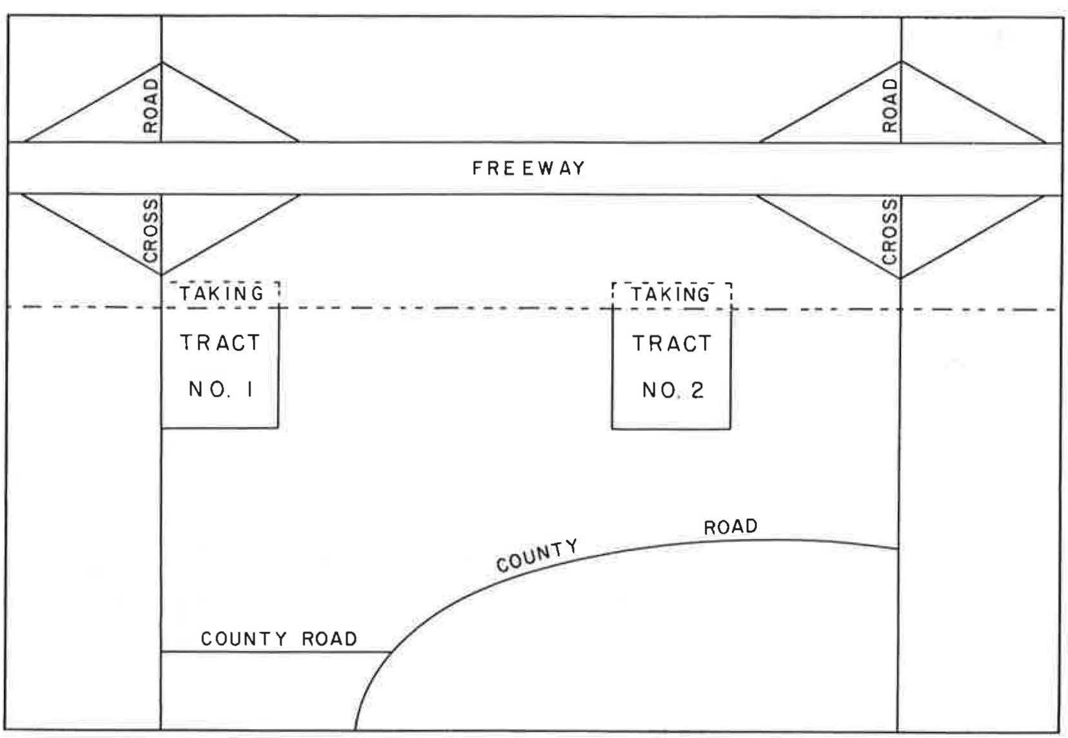


Figure 2.

length is not a major factor because access to the freeway can be gained by way of the crossroad and signs can be erected that are clearly visible on the freeway. The same size tract of land located adjacent to the freeway but midway between interchanges (Tract 2) is in theory similar to Tract 1 in value but is not subject to nearly as great a change in value as that tract because it does not have access to the freeway. Assuming that there are no severance damages to either tract and that each still has the same access to the public road system it had before the freeway, each should theoretically be treated the same as far as right-of-way costs are concerned. This is where the similarity stops, however, because Tract 1 is, as has been pointed out, subject to an immediate enhancement in value by reason of its location at a crossroad, whereas Tract 2 is not. A frontage road along the freeway tends to equalize the effect that the freeway has on the two tracts.

It may also be pointed out that the same comparison might be drawn between two pieces of property, one on the freeway and one a mile away. No immediate value enhancement is realized by the one a mile from the freeway. This is probably true, but no right-of-way dealings are necessary with the property a mile away, whereas it is necessary to secure property from both Tracts 1 and 2, and the inequality is evident to all concerned including a condemnation jury if it is necessary to go to condemnation to secure the needed right-of-way. Experience has shown that these juries are prone to attempt to compensate the owner of Tract 2 for the fact that he is not getting as advantageous an arrangement as the owner of Tract 1. How much additional compensation the owner of Tract 2 should have is something of a guessing game and can vary tremendously.

If a frontage road is provided, Tract 2 has approximately the same access to the freeway as Tract 1 and will enjoy about the same value enhancement as Tract 1. The frontage road also tends to spread the value enhancement over much more property and usually results in less enhancement to a few tracts that happen to be advantageously located while affecting a great many more properties.

Dual Appraisal

In attempting to learn exactly what effect these various treatments will have on the cost of right-of-way, the practice of dual appraisals has been employed on various occasions. Each tract along the freeway route which must be secured as right-of-way is appraised as if the freeway had frontage roads and again as if it had not. The additional cost of securing right-of-way without frontage roads is then compared with the cost of building frontage roads. The cost of frontage roads can be determined with some degree of accuracy and therefore is a reliable figure. The actual cost of right-of-way is not as easy to determine, and reliable appraisals may sometimes be just so much paper when a skilled lawyer finishes tearing them to pieces. Dual appraisals do, however, give a fairly reliable indication of relative costs, and the exact costs can be determined when a final settlement for the property in question is reached. Each case can become final only one way, however, either with frontage roads or without, and it is never possible to know what the final outcome of more than one of the possibilities for a particular piece of property might have been. Similar cases can be compared, however, and yield some interesting results.

In one instance a value of approximately $106,000 was appraised for negotiation for two parcels of land. No frontage roads were to be provided. A commissioners' award of $349,000 was rendered on the grounds that the remaining property was not adequately served. The case was appealed. At the jury trial, the property owner gained additional access across the freeway and was awarded $193,000 compensation and damages. Frontage roads were still not included, but the owner received 182 percent of the appraised value of the taking and it is very likely that at some future date frontage roads may yet be constructed to serve this and additional property in the area. Frontage roads could have been provided initially for about $130,000.

In another case, which is still on appeal, the appraised value of $17,000 went up to a jury award of $295,000, the lack of frontage roads being the prime issue. This is obviously a somewhat ridiculous situation and will undoubtedly be adjusted in the courts, but this right-of-way will cost more than it should and the entire problem could probably have been avoided if frontage roads had been provided in the original design.

TABLE 1

RIGHT-OF-WAY COST DATA ON A SMALL CITY RELOCATION

Parcel	Offer ($)	Jury Award ($)	Difference ($)	Cost of Frontage Roads ($)
2	3,575	10,230	6,655	2,216
5	13,150	17,960	4,810	186
9	5,095	9,500	4,405	5,980
11	1,217	3,673	2,456	2,240
15	1,190	2,500	1,310	1,976
19	1,600	7,000	5,400	Whole taking
23	330	2,383	2,053	308
25	4,900	19,260	14,360	4,949
28	1,535	3,237	1,702	1,242
31	4,005	16,500	12,495	3,847
34	3,583	9,690	6,107	2,194
Total	40,180	101,933	61,753	25,138

Another example is given in Table 1. The properties here were secured with the understanding that frontage roads would not be constructed. This is a relocation route around a town of 6,500 people and will probably be subject to a limited amount of development. Although this is not exactly a case in point, the evidence considered by the court indicated that the fairly considerable difference between the offer and the jury award was due to the lack of access. The construction of low-type frontage roads would have resulted in some saving in the overall cost of the facility.

These are not necessarily typical examples of the relative cost of providing frontage roads vs securing access rights because a review of numerous cases indicates there is no such thing as a typical case. These examples do indicate some of the problems involved, and numerous additional cases that have been reviewed disclose that the situation can be summarized as follows: Where the freeway is located in an area subject to any change in land use, which possibly can be used by the landowner as a point in right-of-way dealings, then construction of frontage roads will usually result in an immediate saving in overall cost of the freeway development. It is not necessary that this possibility of land-use change be too apparent or immediate.

The greater the possibility of development and the greater the potential of the area to support development, the greater the likelihood that frontage roads will prove to be economical. All of this is exclusive of value enhancement, which is enormous in some cases.

Property Value Enhancement

Numerous studies of the influence of freeways on land values have been conducted. The fact of enhancement is well established in most cases. The amount of enhancement and the countless interacting influences among such factors as specific location, type of land use, area influence, the passing of time, and traffic generation are the subject of much study and more is certainly needed.

In specific cases, land value enhancements in Dallas and Houston have ranged up to more than 600 percent in a few instances, with increases of 300 to 400 percent not uncommon. These freeways have frontage roads, however, so there can be no comparison with what the enhancement would have been without frontage roads.

In San Antonio a study by Adkins and Tieken (3) completed in 1958 drew comparisons between sections where property had access to frontage roads and where property lay adjacent to the freeway right-of-way but did not have access to it. Result of this comparison indicated the value of the property with frontage increased approximately 40 percent more than that without during the study period. Property used for nonresidential purposes where access to a frontage road was provided increased approximately 150 percent more than property that lay adjacent to the freeway but did not have access to a frontage road. This is a relatively limited amount of data and certainly could not be considered conclusive, but when all the circumstances are considered, there is every reason to believe that this condition would prevail on most freeways. Most businesses are dependent on street access to some degree and it is logical that those that are dependent on a large number of people getting to the business would pay a premium for a location on a freeway frontage road.

Several other factors may or may not show up in a cost analysis, but are very important in the development of a freeway. One of these is the attitude of the people who operate businesses or own property in the vicinity of the freeway. By and large, these people are convinced that the freeway with frontage roads will be of considerable benefit to them, whereas without the frontage roads the opposite effect will result. Because these are the people who must be dealt with in securing right-of-way for the freeway, this attitude on their part is very important. In several instances where large developments were concerned, the right-of-way for the freeway has actually been donated with the understanding that frontage roads would be constructed. This attitude may also be the difference between securing right-of-way by negotiation rather than condemnation.

OPERATIONAL CONSIDERATIONS

An urban freeway represents a tremendous investment of public funds and it is, therefore, extremely vital to obtain maximum utilization and operational efficiency from such facilities. A good frontage road system auxiliary to the main freeway lanes can greatly aid in obtaining this goal by providing much additional flexibility to the operation of the freeway facility.

Experience with freeways has shown that the development and life of a freeway facility is likely to progress in the following stages:

1. Stage development.—Period during which a freeway may progress from some initial inferior facility to the final design.
2. Freeway construction stage.—Period during which the freeway proper is being constructed.
3. Design life.—Period from completion of the design facility to the time at which design-hour volumes are being exceeded.
4. Saturated operation.—Period during which peak-hour volumes greatly exceed those for which the facility was designated.

Frontage roads are important and useful at all these stages and probably become most vital when stage 4 has been reached. The application and benefits of frontage roads during each of these stages are discussed separately.

Stage Development

In locations around the fringe of heavily developed areas, it is often economical to build the relatively inexpensive frontage roads initially to serve fairly light existing traffic volumes. The more expensive main lanes and grade separations can be added as the need develops. This makes it possible to prorate available money and to get the most use from it. Such a situation is shown in Figures 3 and 4. Figure 3 shows the completed freeway extending into the heavily developed urban area. The freeway transitions into the more economical frontage-road-only design at the edge of the developed area. As time passes and the development moves out, the freeway can be extended. Figure 4 shows more details of the transition. This arrangement allows extreme flexibility because all right-of-way is acquired at the time of the first development and frontage to all adjacent property is provided initially in such a manner that revision should not be required when the freeway is developed. This arrangement may require a heavier pavement design on the frontage road than would otherwise be required but the cost of this is usually justified, particularly if construction of the freeway lanes can be deferred for a substantial period of time.

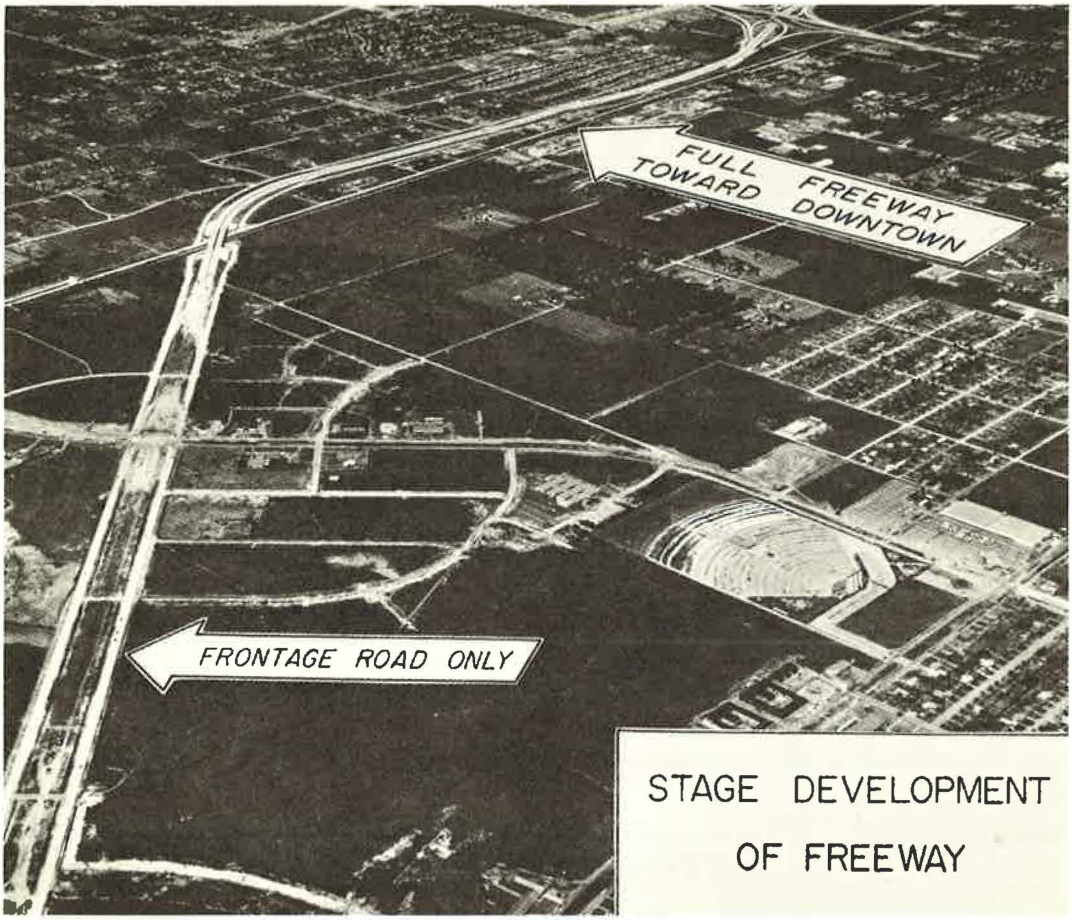


Figure 3. Completed freeway extending into heavily developed urban area.

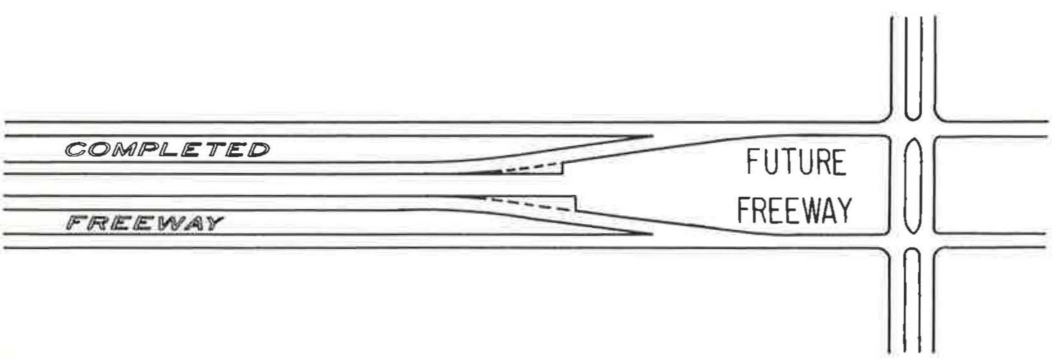


Figure 4. Transition from freeway to frontage road section.

Construction Stage

During the time the freeway is being constructed, the frontage road also serves a very important function. A possible sequence of the development is shown in Figure 5. Traffic remains on the existing road while the frontage roads are being constructed. Connections to adjacent property, etc., can be made during this stage. On completion of the frontage roads, the traffic can be rerouted to them and can operate with reasonable efficiency during the period in which the freeway lanes are being constructed. The

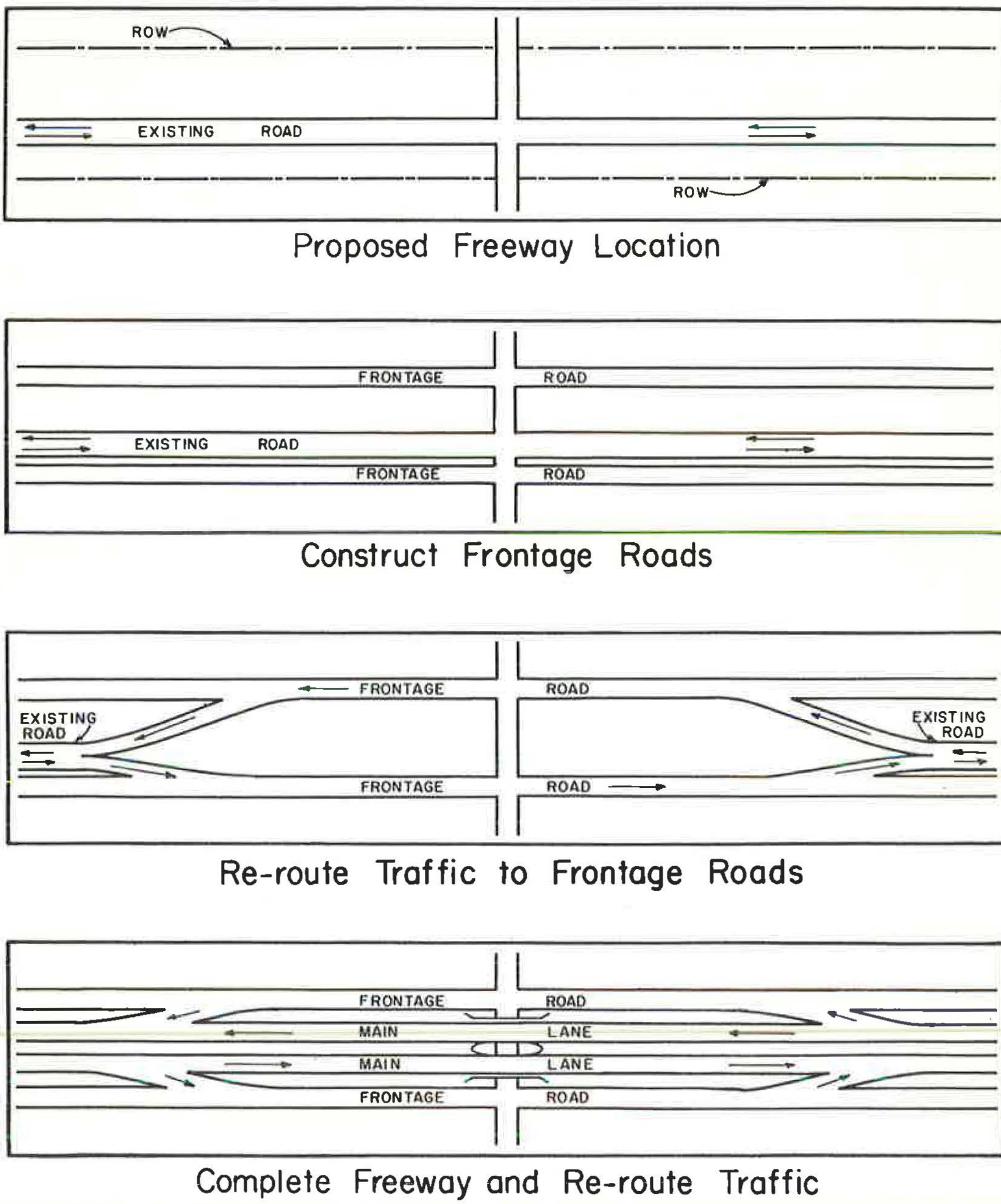


Figure 5. Stage development of freeway.

figure is an extremely simplified version of the development sequence that would probably take place in several additional steps but it illustrates the part that the frontage roads play in such a development. This procedure may not be necessary where a good street network is available for use as a detour, but even with some available streets this arrangement will eliminate the many problems arising from trying to use local or residential streets as detours for heavy arterial traffic during the period of freeway construction.

Design Life

During the design life or period of normal or design operation of a freeway, a frontage road system can add much to the overall operational efficiency of the facility. Some of the specific areas in which substantial benefits can be obtained from a freeway-frontage road design are presented.

Land Service.—Although a freeway is designed to accommodate long trip movements, there is no reason why such a facility should not give maximum land service to abutting properties during periods of off-peak flow. This maximum land service helps to realize more gains from the freeway investment and contributes greatly to the transportation needs of the urban area. During periods of peak traffic flow it may become desirable to give greater recognition to the long trip desires on the freeway with a resultant reduction in land service.

A freeway-frontage road system has the flexibility to accommodate both the situations previously enumerated. Figure 6 shows a typical freeway-frontage road system and the accessibility of all abutting properties. This increased land service insures maximum utilization of the freeway. If it is desirable to reduce some of the friction created by numerous entrance ramps during peak flow periods, the ramps may simply be closed and traffic diverted to the frontage road. This could be accomplished automatically with a surveillance system.

Another example of how the frontage road simplifies freeway operation is shown in Figure 7. This situation assumes that a fixed amount of development will exist in the vicinity of the freeway, with frontage either on a frontage road if one exists or on a crossroad. If the frontage develops along the crossroad as symbolized by areas C and D, the round trip path from Point X is shown by the heavy black line to Development C and the diagonal crossed line to Development D. Following these travel paths, it is evident that each requires one right turn, one left turn, and one through movement at a signalized intersection. This is compared with one straight-through movement each at a signalized intersection for vehicles bound to and from Developments A and B located along the frontage roads. Turns at the point of access have been neglected in each case but when considered tend to sway the situation ever farther toward the frontage road. This demonstrates that a given amount of development can actually be served more efficiently if it has access to the frontage road than if it is served by the crossroad.

Interchange Spacing.—In a recent article (4), D. W. Loutzenheiser focused attention on the problem of interchange spacing:

> Proper interchange spacing is receiving much attention. Long distances between interchanges enhance the operation on the through lanes but they may accumulate more traffic than the cross facility is able to accommodate. Closely spaced interchanges provide a better distribution of through traffic and increase the level of local service but with consequent interference to through movements.

With continuous frontage roads and properly designed entrance and exit ramps, the interchange spacing problem can be greatly reduced. As previously discussed, maximum land service (to and from the freeway) can readily be accommodated. The interchange problem is then reduced to one of obtaining sufficient distance between interchanges to permit design of adequate ramps while still permitting arterial streets to cross the freeway occasionally to prevent a "barrier effect" to traffic flow on both sides of the freeway.

Figure 6. Typical freeway-frontage road system.

Figure 8 shows a design that might be considered. In this design, the interchange spacing is increased to permit the provision of numerous on and off ramps. This design permits maximum land service and eliminates much of the need for traffic moving to and from properties abutting on the frontage road to pass through a major interchange. During periods of peak flow, many of the entrance ramps could be closed to minimize influence on main lane movement. Thus, in effect, a freeway with variable interchange spacing could be created.

The maximum spacing between interchanges would be governed by the "barrier effect" created by the lack of through streets crossing the freeway. Considerable research is needed to investigate the extent of such a "barrier effect".

Frontage roads can also aid interchange operation by "spreading" the load, instead of concentrating it at a single interchange. It is possible to accommodate a great deal of interchange movement without vehicles passing through a freeway-major arterial interchange.

On-ramp operation is also benefited by continuous frontage roads as traffic desiring to enter the freeway can be "spread" over more than one entrance ramp. This smooths out the effect of "slugs" of traffic arriving from signalized intersections and permits traffic to keep flowing even though one entrance ramp may be loaded.

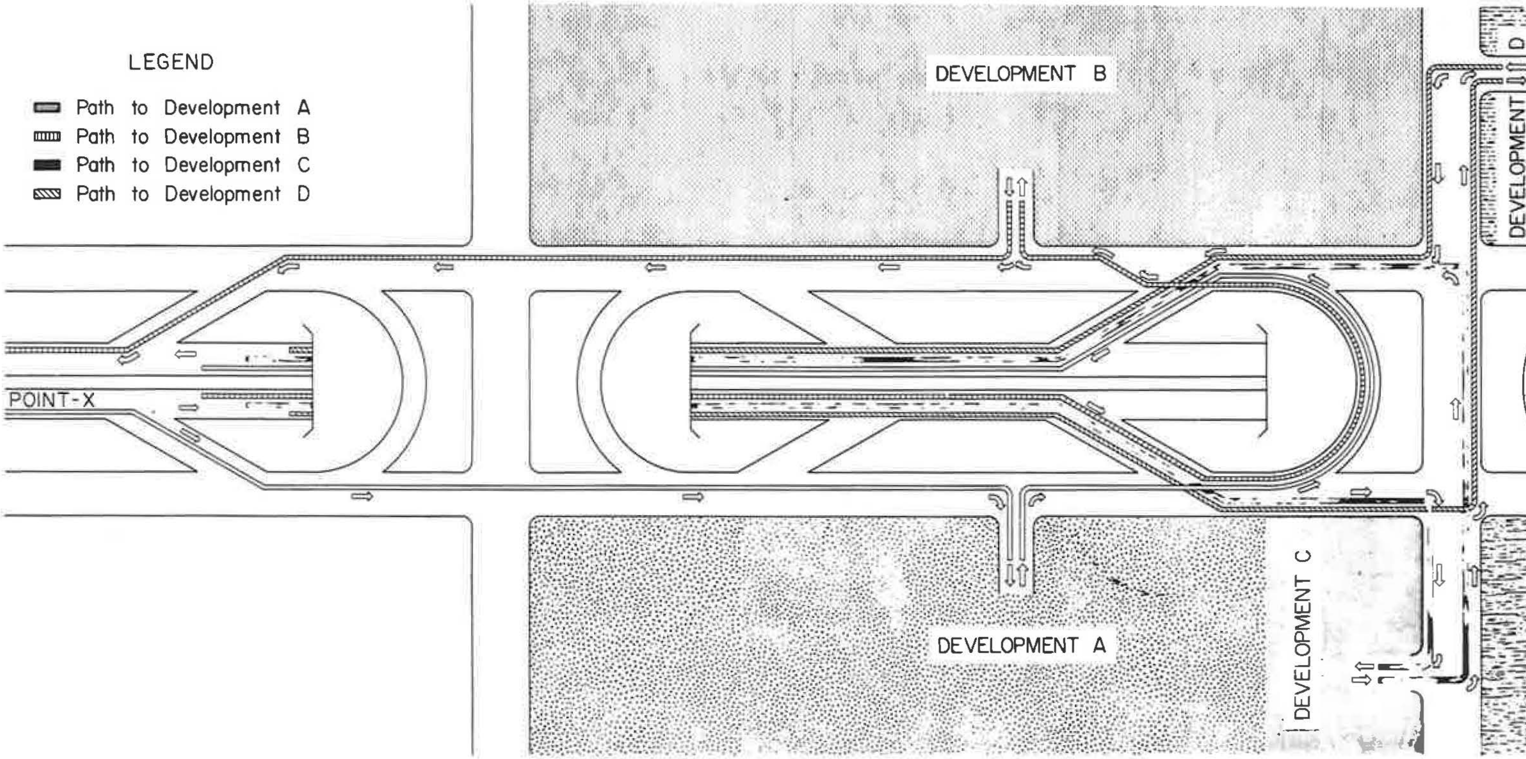


Figure 7. Access paths from Point X to various developments near freeway.

Surface Street Continuity. --One serious disadvantage of an urban freeway without frontage roads is the lack of continuity it creates with regard to the surface street system. This discontinuity is shown in Figure 9 where the "barrier effect" of a freeway without frontage roads is very evident.

With continuous frontage roads as shown in Figure 10, good continuity of the surface street system can be maintained. In fact, the frontage road becomes an extension of the surface system. This continuity is vital to a good traffic flow network. It also adds flexibility to the operation of the freeway as temporary ramp closures are possible without seriously affecting the flow of the system as diverted traffic may utilize the frontage roads.

Special Situations. --During the course of normal operation of a freeway, situations requiring special attention will develop. The following are examples of such situations:

1. When major maintenance is required on the main freeway lanes.
2. When a serious accident occurs on the main freeway lanes.
3. When oversize vehicles such as army transport trucks with high clearance requirements attempt to use the freeway.

In all three cases, a frontage road system provides the needed flexibility to cope with the situation. Figure 11 shows how traffic could be diverted to the frontage road to bypass a maintenance operation or a blocked freeway due to a serious accident. Also in the case of an accident, it is often vital to be able to reach the accident with emergency vehicles as soon as possible. If no frontage roads are available, this may be impossible due to the traffic jam that will probably occur on the main lanes of the freeway. Frontage roads, however, provide a means of quick and direct access to the accident scene. In the case of oversized vehicles with high clearance requirements, rerouting to avoid underpass structures may be required.

Saturated Operation

Many freeway facilities are becoming saturated much earlier than originally planned.

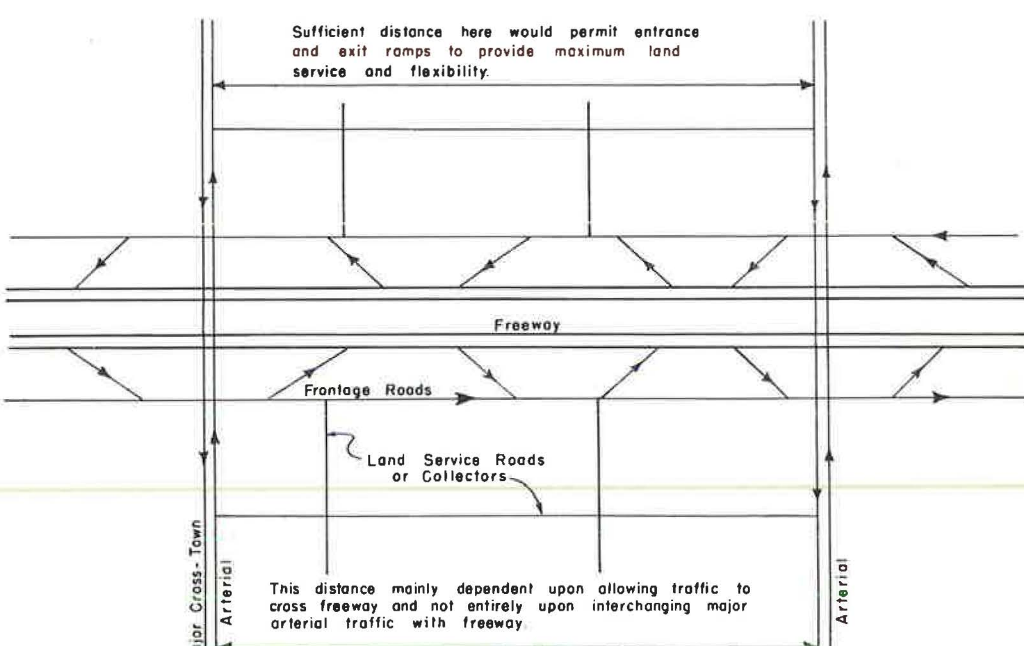


Figure 8. Interchange spacing.

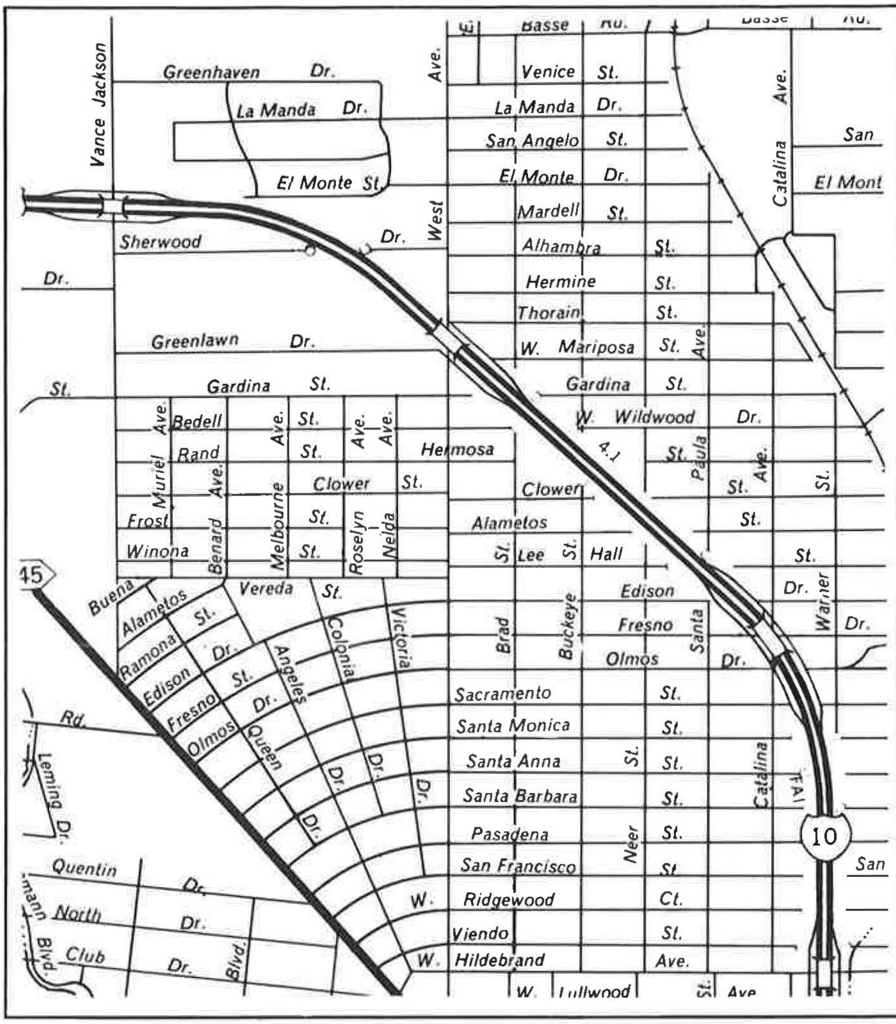


Figure 9. Freeway showing how street system is disrupted by lack of frontage roads.

This has been due mainly to incomplete freeway systems and to rapid increases in trip generation. The saturated flow conditions produce troublesome operation during peak periods of flow and result in facilities operating far below the level of efficiency for which they were designed.

The problem of peak-hour congestion has focused much attention on freeway surveillance and a great deal of worthwhile research is now being devoted to this subject. A question that must be considered, however, is what will be done to improve flow once a surveillance system indicates trouble developing on the freeway. A freeway-frontage road system offers a great deal of operational flexibility and lends itself well to a system of surveillance and control.

First of all, the frontage road provides major street continuity and permits the flexibility of closing off entrance ramps without completely blocking the desired movement of the city's at-grade arterial traffic. Second and probably most important, the frontage road provides additional capacity which can be utilized by the peak-hour freeway traffic. The inherent design of a freeway-frontage road system allows much flexibility of traffic control as various entrance and exit ramps can be opened or closed as the need occurs without seriously affecting the continuity of traffic flow. This condition was rec-

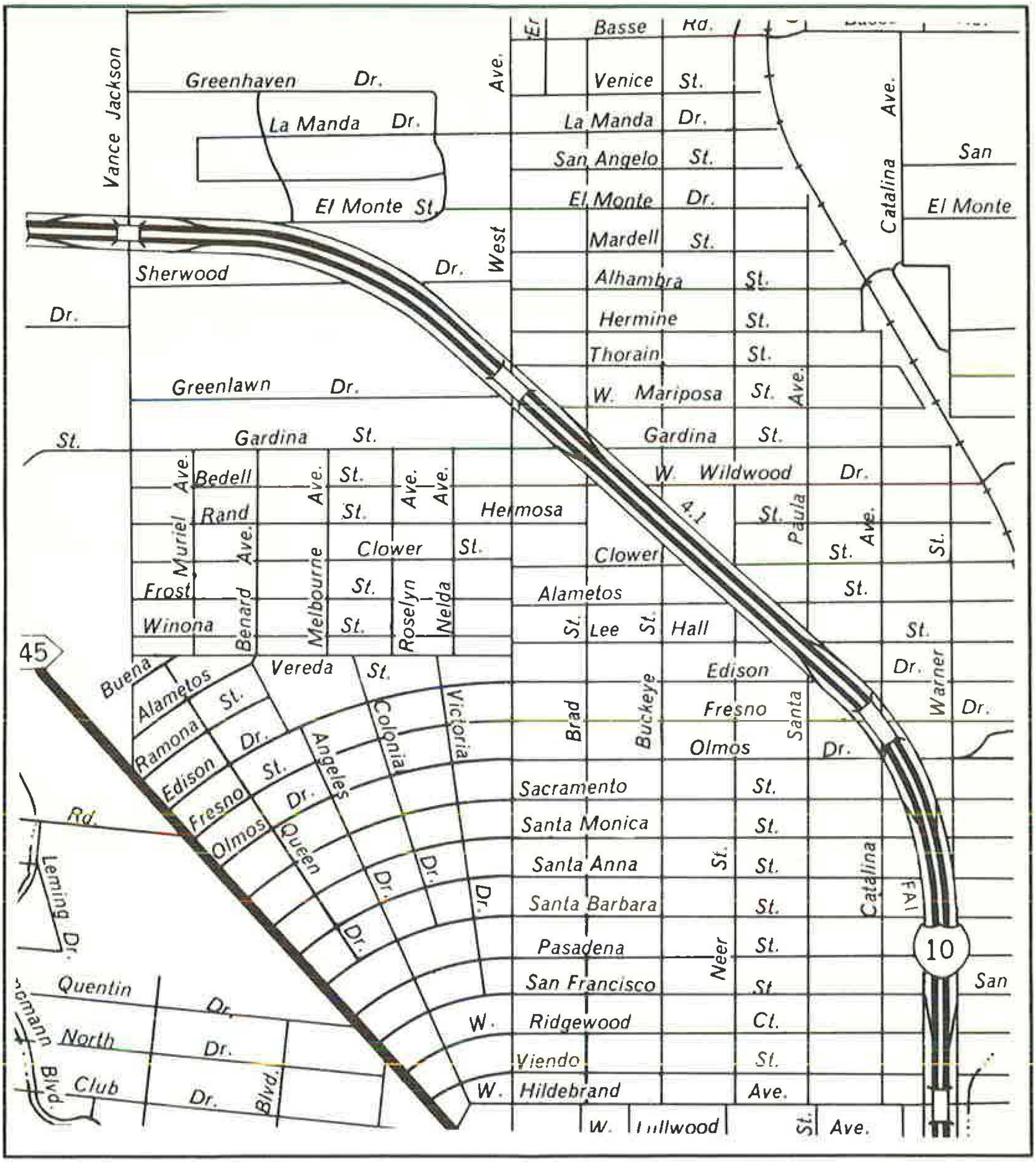


Figure 10. Freeway showing how street system continuity is maintained by frontage roads.

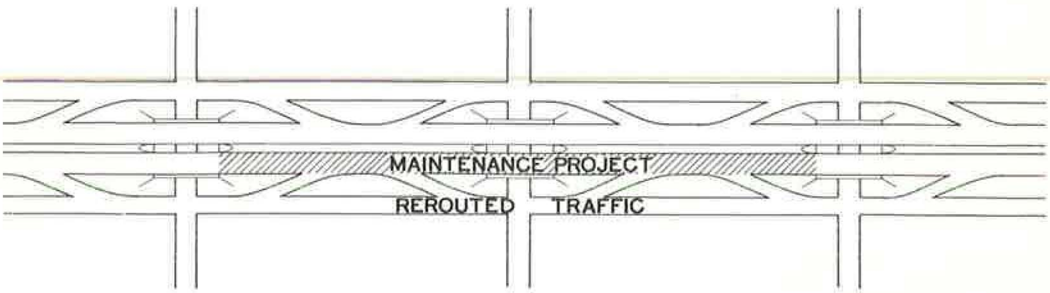


Figure 11. Traffic routed over frontage road during freeway maintenance.

TABLE 2
FREEWAY AND FRONTAGE ROAD VOLUMES, GULF FREEWAY DIVERSION STUDY
7:10 TO 8:10 AM

Study	Ramp	Inside	Middle	Outside	Total	Frontage Road	Grand Total
Houston II	Open	1,752	1,723	1,564	5,039	652	5,691
Houston III A	Closed	1,761	1,779	1,320	4,860	964	5,824
Houston III B	Closed	1,770	1,786	1,279	4,835	937	5,772

ognized by the AASHO Special Freeway Study and Analysis Committee in their report to the Executive Committee (5).

The feasibility of diverting peak-hour traffic to a frontage road by closing entrance ramps was studied by the Texas Transportation Institute on the Gulf Freeway in Houston, Texas (6). Figure 12 shows a section of the Gulf Freeway to which the inbound entrance ramps were closed during a morning peak period of traffic flow. Traffic which normally used these ramps was diverted to the frontage road.

Before- and-after studies were conducted at Point A in Figure 12 through the use of a 16-mm motion picture camera. Table 2 gives results of the volume studies. The diversion resulted in a slight decrease in freeway traffic but an overall gain in traffic moved.

Of more significance, the operating conditions on the freeway were greatly improved. The average 5-min speed during the before study was 23 mph as compared to 36 mph during the after study. Figure 13 shows speed volume relationship comparisons. Travel time studies on both routes (freeway vs frontage road) indicated that the diverted traffic was not subjected to any significant increase in travel time.

The diversion study previously discussed, provided data to indicate that a frontage road could be used during periods of saturated flow to provide added capacity and to improve overall operating condition. Thus, the continuous frontage road is a vital element in the development of a surveillance and control system and provides the required flexibility and added capacity to permit control of freeway and major arterial traffic.

INTERCHANGE CONSIDERATIONS

One major criticism of the use of continuous frontage roads has been that they tend to create problems at points of interchange between the freeway and major at-

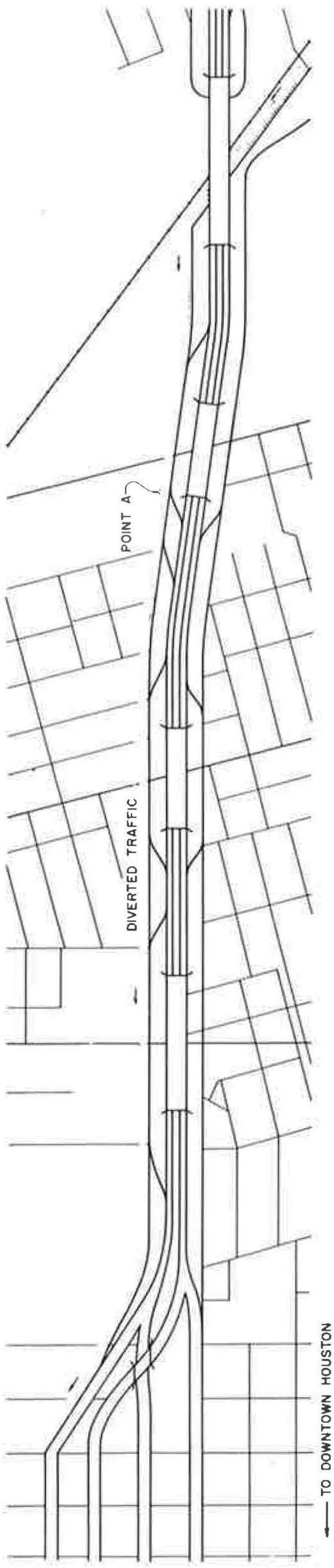


Figure 12. Gulf Freeway traffic diversion.

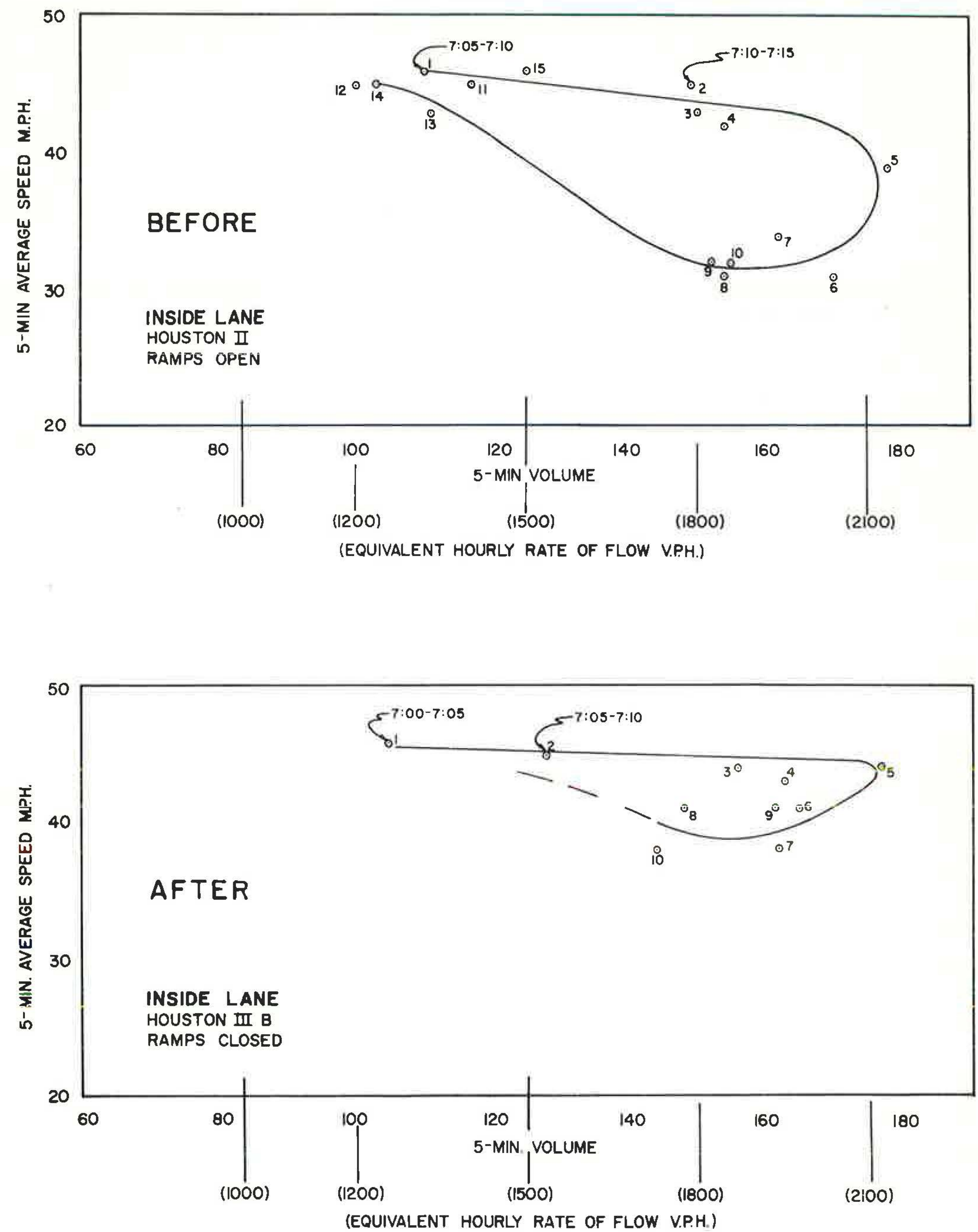


Figure 13. Speed-volume relationships, closed ramp study, Gulf Freeway.

grade arterials. The interchange usually used in conjunction with frontage roads is the diamond interchange and until recently it was felt that this type of interchange had an inadequate capacity to accommodate the movements required.

Recent studies have shown, however, that the diamond interchange when properly designed and signalized has a tremendous potential for the movement of traffic. The two separate intersections created by the intersection of the one-way frontage roads and

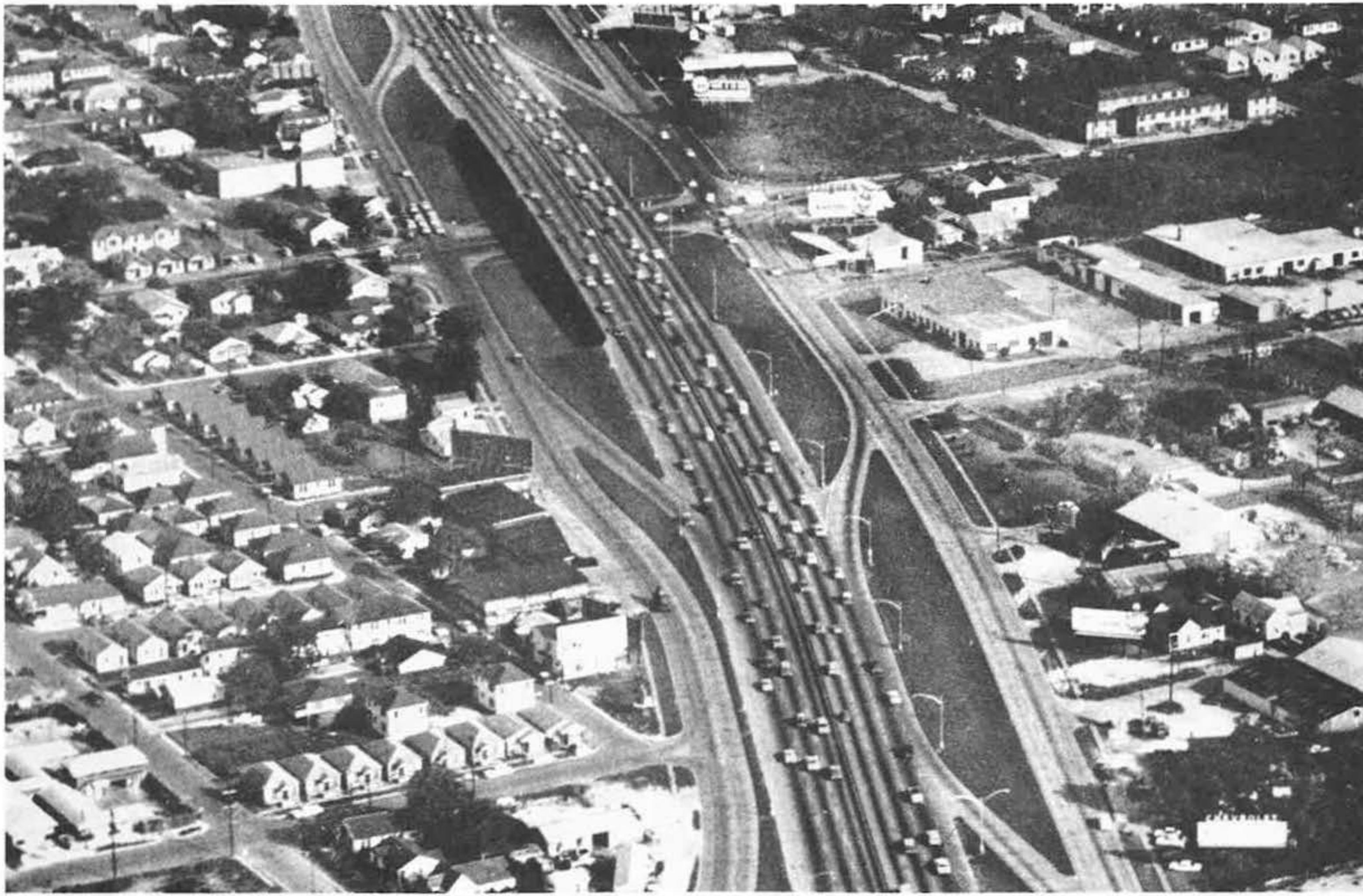


Figure 14. Conventional two-level diamond interchange.

the two-way major arterial permit an overlap of signal phases when the intersection is signalized by a single controller which actually increases the capacity of the intersection area over that of a single intersection with two-way approaches.

A recent report (7) develops the relationship between intersection capacity and signal phase overlap, and it discusses in more detail the development of capacity equations used in this report. Two significant findings reported regarding intersection signalization and capacity are as follows:

1. Intersection capacity can be significantly increased by the use of signal phase overlaps.
2. If phase overlaps greater than 18 sec per cycle can be obtained, maximum capacity can be obtained with cycle lengths of 50 to 70 sec.

Variations of Diamond Interchange

The diamond interchange permits a wide range of design flexibility in that several variations of a diamond interchange can be used. The three basic variations of a diamond interchange are (a) conventional two-level, (b) split two-level, and (c) three-level. The capacity of the diamond interchange depends on the type selected.

Conventional Two-Level.—The conventional two-level diamond interchange shown in Figure 14 is the most widely used variation of the diamond interchange. The signal phasing shown in Figure 15 permits a signal phase overlap and yields a basic capacity relationship:

$$N_c = 1,714 - \left(\frac{18.4}{2.1}\right)\left(\frac{3,600}{C}\right) + \left(\frac{\phi}{2.1}\right)\left(\frac{3,600}{C}\right) \qquad (1)$$

in which

N_c = basic capacity (capacity considering only one approach lane per phase) in vehicles per hour;
C = cycle length in seconds; and
ϕ = total signal phase overlap time in seconds.

Eq. 1 can be explained by considering each individual term. The first term (1, 714) represents the number of vehicles that can be moved from a single approach lane per hour at an average time spacing of one vehicle every 2.1 sec. The second term represents the number of vehicles "lost" per hour due to starting delays and amber time, and the final term represents the number of vehicles "gained" per hour due to signal phase overlap. Thus, an ideal volume (1, 714) is adjusted to the actual volume (N_c).

When C = 50 sec and ϕ = 20 sec, the basic capacity of the signalized intersections of a conventional two-level diamond is as follows:

$$N_c = 1,714 - \left(\frac{18.4}{2.1}\right)\left(\frac{3,600}{50}\right) + \left(\frac{20}{2.1}\right)\left(\frac{3,600}{50}\right)$$

$$= 1,714 - 630 + 680$$
$$= 1,764 \text{ vph}$$

For an interchange with three lanes per approach, the total hourly capacity of the intersection area (N_T) is N_T = 3(1, 764) = 5, 292 vph. This total capacity of 5, 292 vehicles per hour can be apportioned to the various approaches on the basis of percent green time available for each phase (or approach). A specific example of possible volumes that could be handled is shown in Figure 16.

Split Diamond.—If more capacity than that provided by the conventional diamond is required, a split diamond design can be used. This design as shown in Figure 17 is obtained by dividing (splitting) the major arterial into two one-way streets at its intersection with the freeway-frontage road system. The major arterial could be a one-way pair or could be transitioned back to a two-way street a short distance from the freeway.

The main advantage of this design is the added intersectional capacity that can be

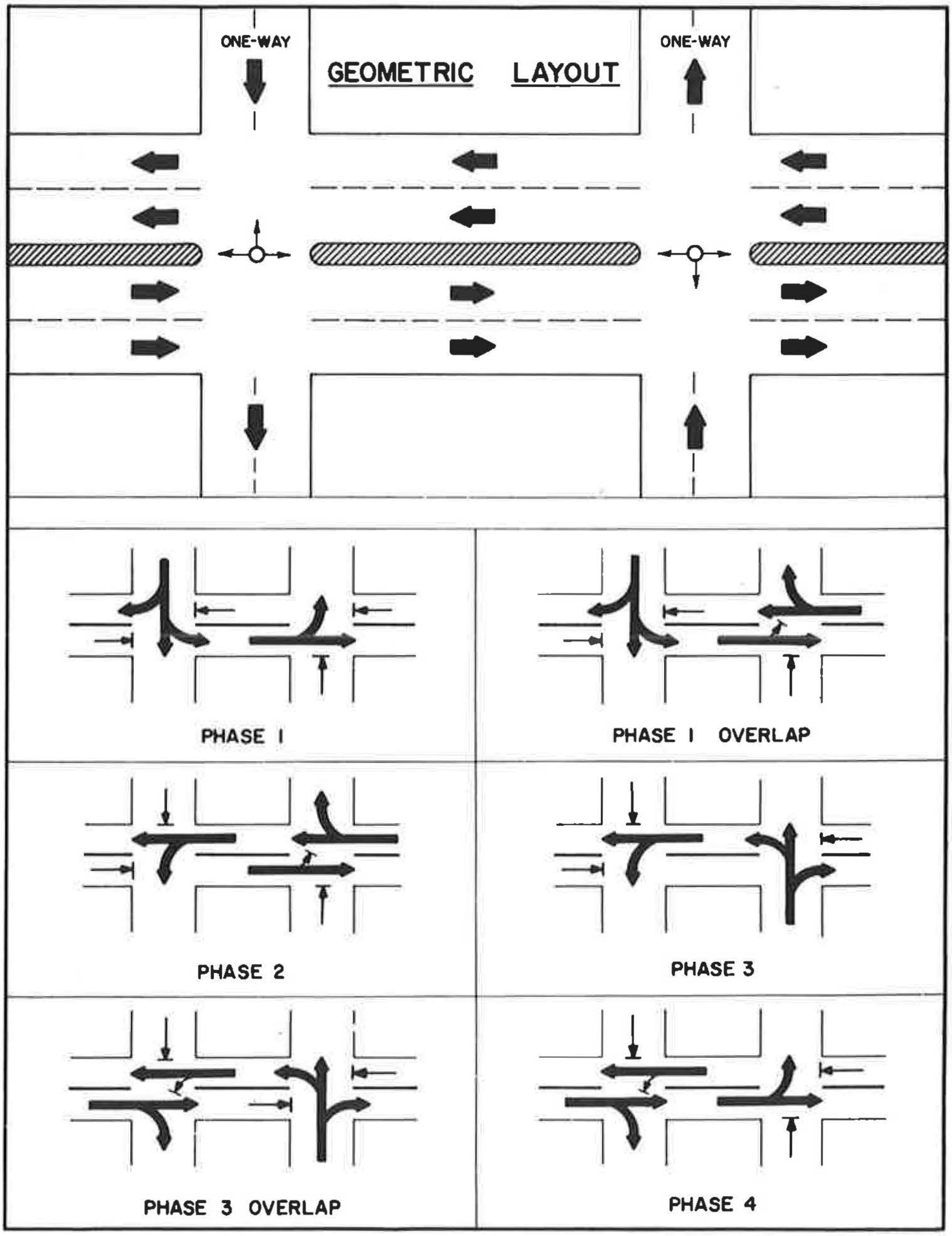
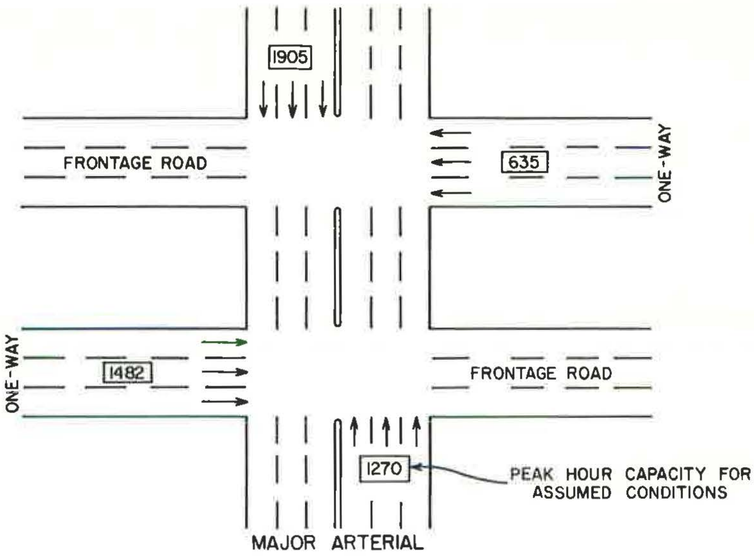


Figure 15. Signal phasing, conventional two-level diamond interchange.

obtained due to the overlap signal phasing which is possible. Figure 18 shows the desired phasing arrangement from which it can be observed that four phase overlaps are now possible compared to only two with the conventional two-level diamond.

The basic capacity equation (Eq. 1) will still hold for this interchange with the exception that a longer cycle length will be required and that ϕ will be increased. The longer cycle length is required to assure ample overlap time on each phase, and ϕ increases due to the increased number of overlaps. If $\phi = 40$ sec (10 sec per phase) and C = 80 sec, then N_c = 1,714 - 390 + 860 = 2,184 vph.



	PEAK HOUR CAPACITY	POSSIBLE ADT VOLUME
MAJOR ARTERIAL	3175	31,750
FRONTAGE ROAD	2117	21,170
CRITICAL CAPACITY	5292	52,920

ASSUMPTIONS

MAJOR ARTERIAL TRAFFIC IS 60% OF TOTAL INTERCHANGE TRAFFIC AND IS SPLIT 60-40.

FRONTAGE ROAD TRAFFIC IS 40% OF TOTAL INTERCHANGE TRAFFIC AND IS SPLIT 70-30.

PEAK HOUR VOLUME - 10% ADT

Figure 16. Interchange capacity, conventional two-level diamond interchange.

Again considering an interchange with three lanes per approach, the total peak-hour capacity of the split diamond is N_T = 3(2, 184) = 6, 552 vph, which is an increase in capacity of 1, 260 vph as compared with the conventional two-level diamond.

Three-Level Diamond. —If neither the conventional two-level nor the split diamond interchange provides the desired capacity, a third variation termed a three-level diamond can be used. This interchange is shown in Figure 19. This interchange carries the major arterial traffic over or under the freeway on a separate (third) level. The interchange movements between the major arterial and the freeway (or vice versa) are accommodated through an intersection area that can be designed and operated exactly like the intersection area of a split diamond (Figure 17).

The intersection capacity of the split diamond (as previously developed) is therefore available to accommodate the interchange movements. The through traffic on the major arterial and freeway travel on separate levels and enjoy uninterrupted flow capacity. Heavy left-turning movements can be handled by the use of dual turn lanes. Heavy right-turn movements can use separate right-turn lanes or loops. Thus, the capacity of a three-level diamond can approach that of a directional interchange.

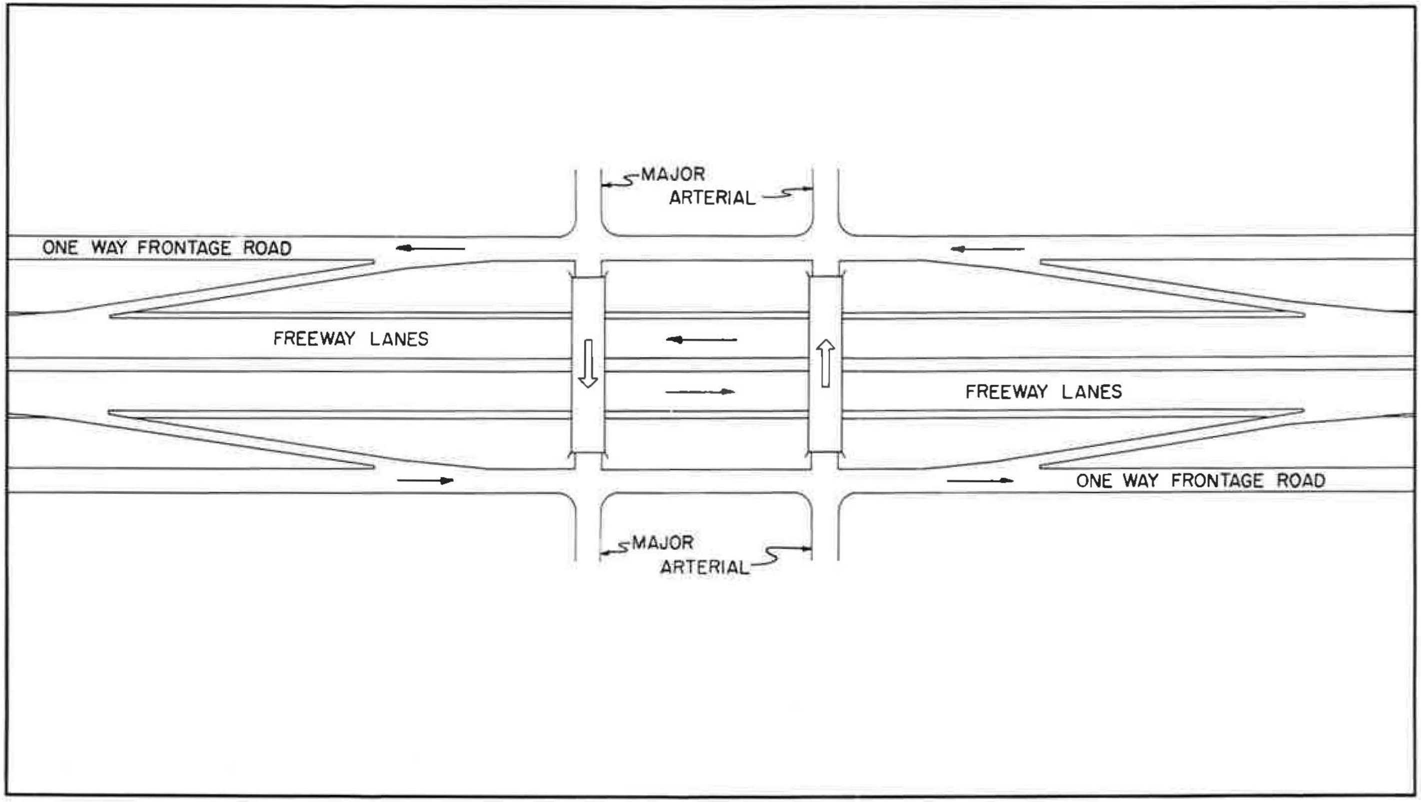


Figure 17. Split diamond interchange.

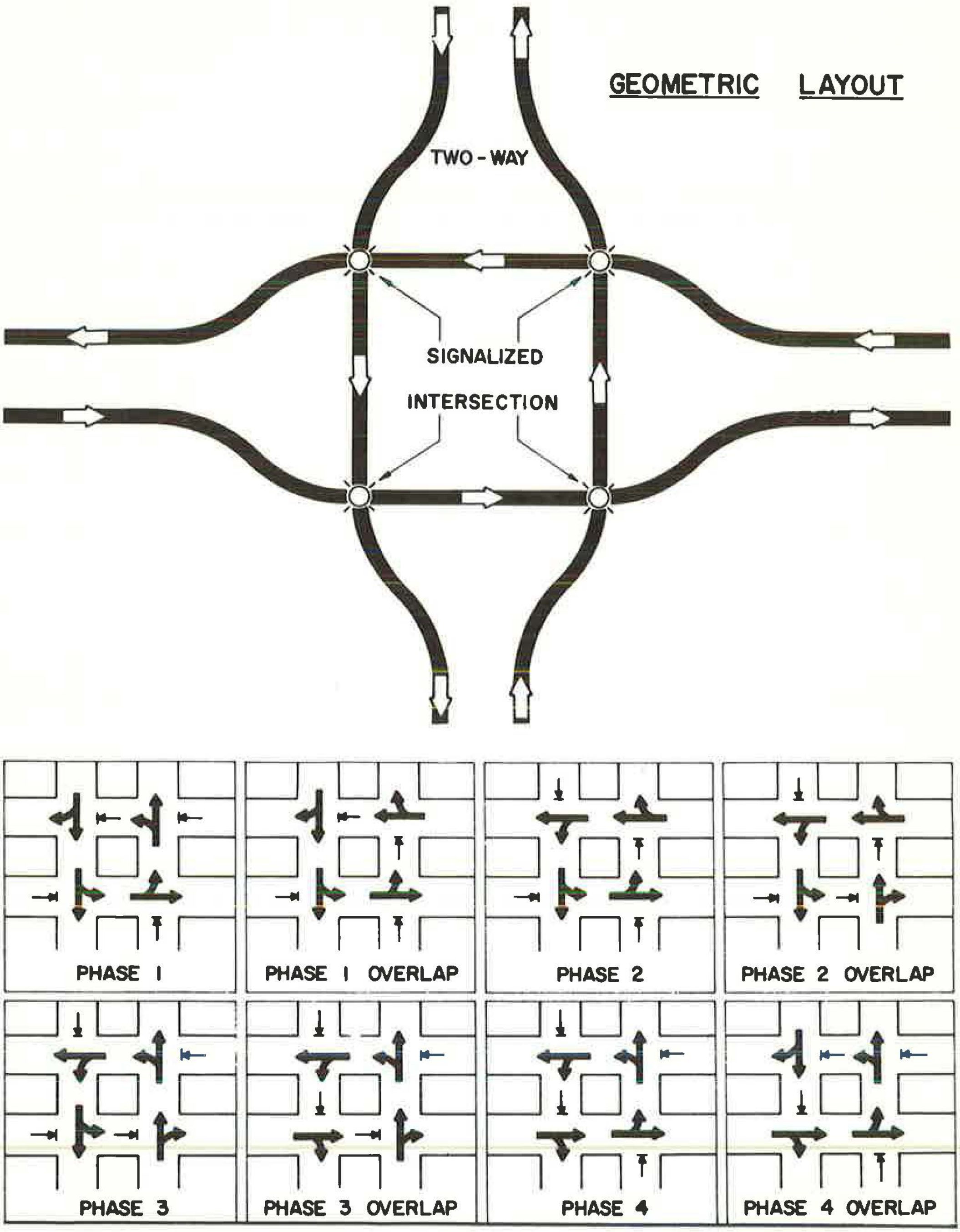


Figure 18. Signal phasing, split or three-level diamond interchange.

Figure 19. Three-level diamond interchange.

SUMMARY AND CONCLUSIONS

This paper has evaluated the use of frontage roads as an element of urban freeway design. The following conclusions are presented in summary of the evaluation:

1. In view of the effect that the presence or absence of frontage roads has on the cost of right-of-way, the construction of a frontage road system will usually result in a lesser overall cost for the entire facility.
2. The presence of a frontage road adjacent to a freeway tends to equalize the effect of the freeway on adjacent property, to minimize difficulties in right-of-way acquisition, and to distribute the benefits of the freeway more evenly.
3. The frontage road is more than an appurtenance to serve adjacent property. It is a multifunctional, integral part of the overall street system and is beneficial to the operation of the system in many ways.
4. A continuous frontage road system is an asset to a feasible and operationally efficient means of using a stage development program for the construction of urban freeways.
5. A continuous frontage road system provides a means of handling traffic flow during the construction of the main freeway lanes.
6. During the design life of a freeway facility, a continuous frontage road system provides maximum land service to properties abutting the freeway. It greatly increases the flexibility of the interchange system and provides surface street continuity. In addition, such a system provides operational flexibility to handle special traffic situations which may develop.
7. When a freeway reaches a saturated flow condition, a frontage road system can provide the operational flexibility required to operate a system of freeway surveillance and control.
8. The design of a freeway-frontage road system presents no special design problems, and interchange movements can usually be handled with some variation of the relatively inexpensive diamond interchange.

In the past, the frontage road has usually been viewed only as a means of controlling access, and little attention has been focused on the operational advantages such a facility offers. It is hoped that this paper will serve to point up the advantages of a continuous frontage road and to stimulate the freeway designer to give serious consideration to this facility as an essential design element of future urban freeway systems.

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