

Highway Design for Safety

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INTRODUCTION

Early in the 1900's, as the number of automobiles increased and the quality improved, there came a public demand for all weather roads—roads that would have at least acceptable surfaces in any of the worst weather. Everybody wanted his road fixed so there was a need to spread the tax dollars as thin as possible and still accomplish the all weather surface. When the driver got his all weather surface, it was thought that it was as much as he could expect. As far as safety was concerned, he was pretty much on his own. Road design for safety was generally considered too expensive. Early design hugged the ground with profiles and put sharp curves in to save a little excavation here and there. Excavation was expensive in the days when slip scoops and mule teams were used. Ditches were built close to pavement edges and bridges were quite narrow. Too many things were done to spread the tax dollars. Statistics will bear this out as fatality rates per miles traveled were much higher in the 1930's than now.

At present there is a new emphasis on safety. Now about everybody is out of the mud with all weather roads. We are more affluent. We afford more and better cars. Hence, we can afford safer and better roads. We are in a period of design where the accent is on safety. Safety should no longer be spared to spread road tax dollars. It is better that many wait for a safe road rather than everyone getting half safe roads a little sooner.

Some of the new safety features being accepted are: (1) limited access (2) dual lane highways (3) median barriers (4) long sight distance by flat grades, flat curves, both vertical and horizontal, and (5) highway lighting.

The AASHO Manuals (rural 1965 and urban 1957) give many minimum standards for design which must be adhered to. However, it is important that in most cases these minimum standards be exceeded. Quite often it is possible to go well above minimum standards without the expenditure of many more dollars, and buy quite a bit more safety.

GEOMETRIC DESIGNS FOR SAFETY

Fig. 1. shows our problem. It is a car out of control. It hits something either on the road to the right or to the left or it rolls down a steep slope. The driver shouldn't do this. He should keep the car on the road and allow for things in front of him. However, human beings are fallible and it behooves us to design highways with this in mind. Some people who will drive our highways will drive them at high speed. It is always possible that many of them will let their cars get out of control. When this happens, and if they don't hit anything, they probably won't be hurt. We must try to design to take care of the speedster who has let his car get out of control.

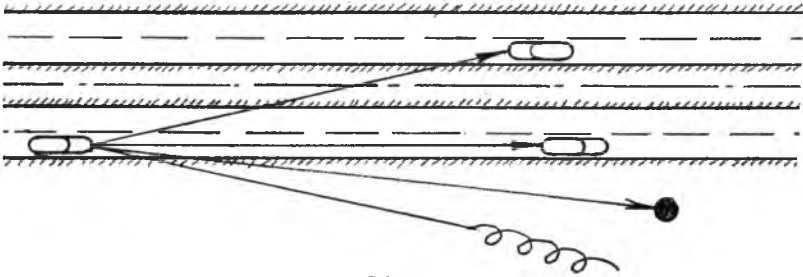


Fig. 1.

Wide, Flat, Open Grades

To do our best, we must have an ideal. Fig. 2 shows an ideal safety cross-section. For the ideal road, the divided lane pavements are far apart, the ground is perfectly level and there are no obstructions of any kind to be hit. The driver can run off the road with almost no chance of getting into serious trouble. There is just nothing in the way to cause a wreck. However, it is apparent to those who know something about roads that this ideal safety cross-section has faults. First, drainage is poor. Second, there is too much right-of-way—it would be hard to justify such a wide level swath. Thirdly, if we are to tell people where to go, warn them of exits and obstacles, etc., we need signs and sign posts. Lighting posts are needed to light the area at night. So we are going to build some of our own dangerous fixed objects.



Fig. 2.

Fig. 3 shows a cross section which is not as flat as the ideal, but it does provide drainage with acceptable 6:1 slopes. Note the ditch is located a little distance from the pavement. It is quite important that this pavement be drained satisfactorily. If not it will tend to break up from freezing and thawing, etc. However, a granular subbase has been placed underneath the pavement and extended through the shoulders to the ditch. Also at times subsurface drains are built along the pavement edge. The 6:1 slopes came from research at the General Motors Proving Grounds. It has been determined that a 6:1 slope is reasonably safe. It will provide satisfactory drainage and can be put into back slopes. Cars out of control are not too likely to turn over on it. Note in Fig. 3 that the desirable minimum distance to the nearest obstacle is given as 30 feet. Research in New York has shown that 80 percent of the fatalities occurring by cars running off the road hitting fixed objects, occur by hitting objects within 30 feet of the pavement. New York is making an effort to clear the right-of-way of all obstacles out as far as 30 feet. Another feature of the section in Fig. 3 is a stabilized shoulder which provides for recovery of a vehicle off the pavement and for emergency stopping.

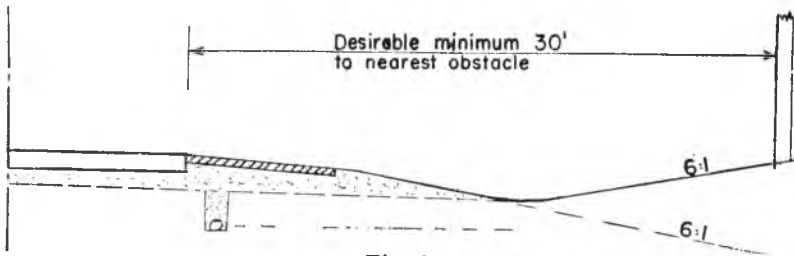


Fig. 3.

Radius Tangent to Shoulders for Private Drives

In Fig. 4 is shown a two lane highway with stabilized shoulders and approaching it is a private drive. The stabilized shoulders have been a wonderful addition to our highways. They provide for a recovery and an emergency stop and can be used as a deceleration lane for minor approaches. The right turn radius for the private drive should be tangent to the stabilized shoulder. The radius shown dashed encourages deceleration in the through lane. A driver decelerating there slows down, and becomes an obstacle to be hit from the rear. Such a vehicle can be the cause of a serious accident. Note also that the stabilized shoulder can serve as a passing lane to pass cars that are waiting to turn left into the private drive. The additional private drive pavement required by the radius tangent to the stabilized shoulder is small.

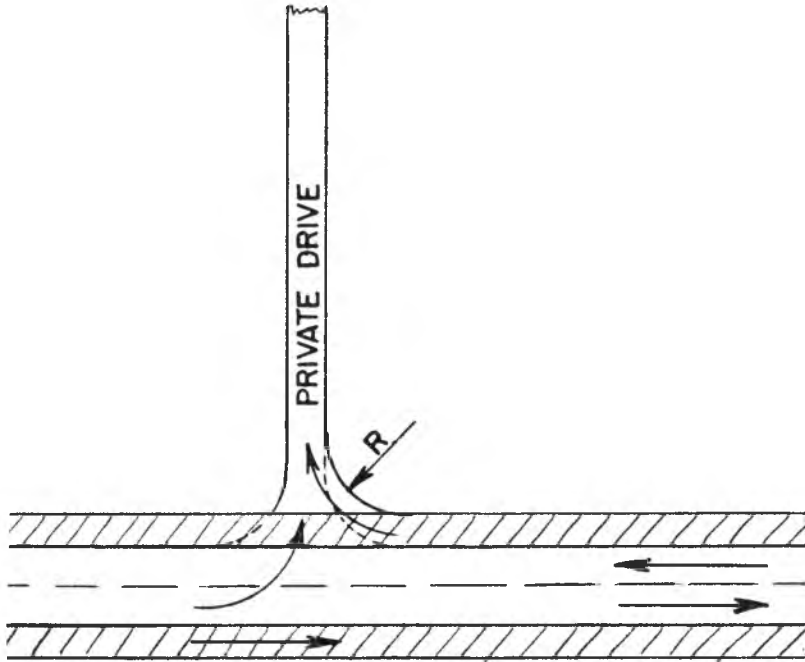


Fig. 4.

Not many dollars are involved. However, the radius tangent to the shoulder can materially add to the safety of the drive.

Turning Lanes

Fig. 5 shows a minor cross road crossing a dual lane highway at grade. The full set of turning lanes is shown along the dual lane highway. It is very desirable to have these for safety reasons. Capacity wise there may be no need for them, but on our modern dual lane highways, in rural areas, no one expects anyone to slow down on a thru lane to make a turn. When someone does slow down, the turning vehicle becomes a dangerous obstacle. Also, when deceleration lanes are provided, it becomes important to have recovery lanes so that vehicles that drift over in the lane not intending to make the turn, can get back onto the thru pavement. The AASHO manuals have tables giving lengths needed for these lanes and tapers.

Deceleration Lanes

The outline of our present freeway deceleration lane is shown in Fig. 6B. It is long with some parallel lane width followed by a flat exit angle, allowing for a very easy, fast exit from the thru lane so the

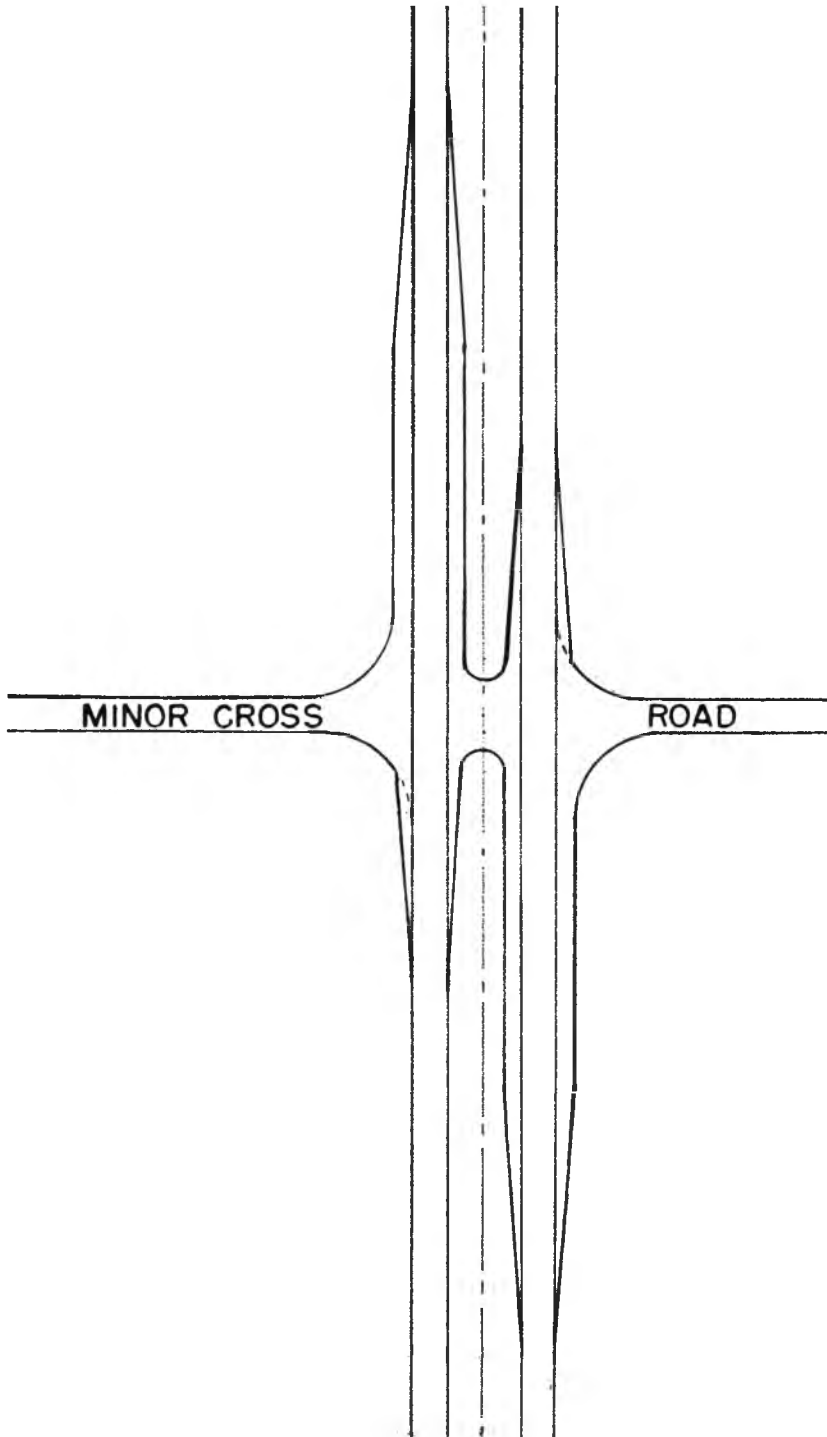


Fig. 5.

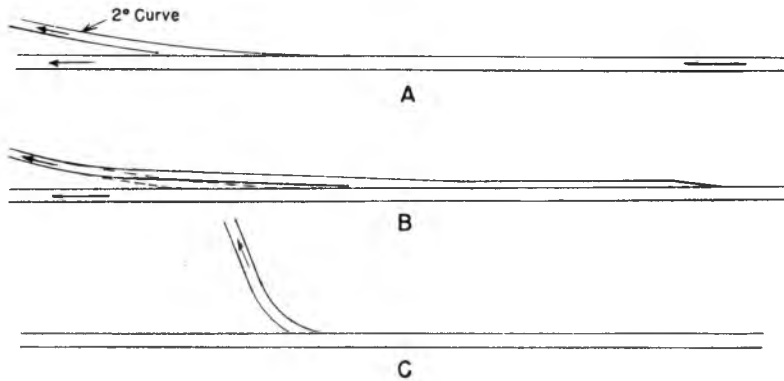


Fig. 6.

driver has no need of decelerating in the thru lane. His exit is about as easy as we can possibly provide for. This standard has evolved thru experience. In Fig. 6A, the exit is a two degree curve tangent to the thru pavement. The table "Safe Speed on Curves", shows that a driver can peel off safely at 80 mph—this should be fast enough for anybody. If he can do this on this kind of an exit, why build all that extra pavement shown in Fig. 6B? The reason is that the driver's eye is about three feet above the pavement. He sees everything edge on. He seldom has a plan view of the geometrics that he is approaching. The designer needs to get his eye down to the edge of the drawing board to get a driver's eye view of what he is drawing. The exit in 6A would not appear easy but would appear to the driver more like the exit in 6C. The driver would think, "I have to slow down for that sharp turn to the right". When he arrives at the exit in 6A, he would realize that slowing down was unnecessary, but then, by that time it might be too late. He may have had a rear-end collision with a driver that didn't expect anyone to slow down in the thru lane. Much of the concrete in the exit shown in Fig. 6B is for what is called "target value." It is for appearance only. Many of the square yards of pavement will never have a wheel on them probably, but they are quite necessary in order that the approaching driver know that he can exit at high speed.

New Uncurbed Ramps

Fig. 7 shows new and old entrance designs for freeways. Present standards provide stabilized shoulders on both sides of ramps. This is considered safer as curbs are obstacles which can throw cars out of control—the new entrance is quite open. Fig. 7B shows an old curbed ramp entrance with entering vehicles being channelized and shadowed

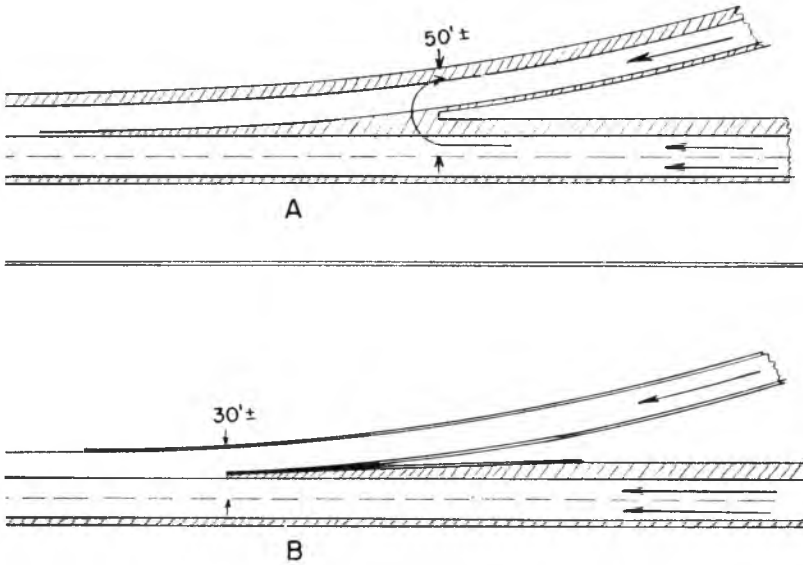


Fig. 7.

from the thru vehicles on the freeway. One effect of curbed entrances was to discourage wrong way turns into the ramp. The 30-foot width shown in 7B is much too short for a U turn from the near thru pavement lane. However, the 50-foot width from the centerline of the thru pavement to the outside edge of the ramp stabilized shoulder is enough for a U turn for all but two passenger vehicles according to our tables. The Lincoln Continental and the Chrysler Imperial might have to have a wheel on the grass if they make a U turn. However, it is an easy U turn for all of the rest. As often happens when something is gained in safety one way, a little something is lost somewhere else. Wrong way movements on ramps are a serious hazard. Wrong way vehicles are quite dangerous obstacles for the legitimate driver. However, the ideal cross-section, which doesn't allow for channelizing curbs, makes everything quite open. The only way to prevent this wrong movement is by education and by signing. The new uncurbed ramps are considered best for overall safety.

Bridge Piers Safely Located

Fig. 8 shows the new two-span structure with piers on the right eliminated. It is more expensive, of course, but is safer. Also, in some interchanges, the elimination of the pier on the right gives more sight distance thru the structure and in this manner provides greater safety. A still better design would be to eliminate the center pier also, but, for

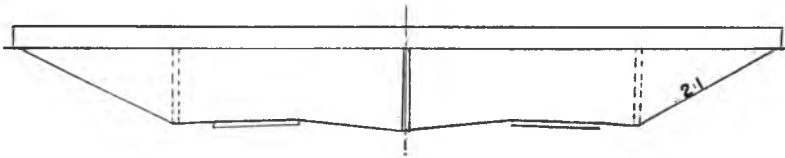


Fig. 8.

free-ways with wide medians that would require quite long spans. It is not being done at present. It is considered just too expensive.

Fig. 9 shows a four-span structure with side pier 30 feet from the pavement. This is still more expensive. However, it has a flatter spill slope and is safer in that manner. There are many variations with flatter slopes, etc., that can be built. In the future we may be building quite open separation structures.

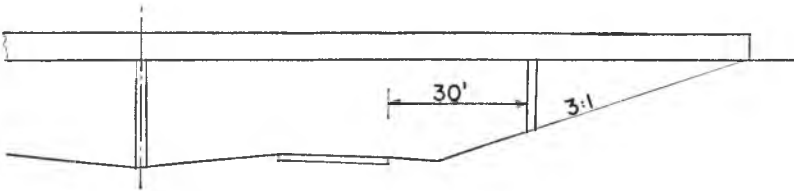
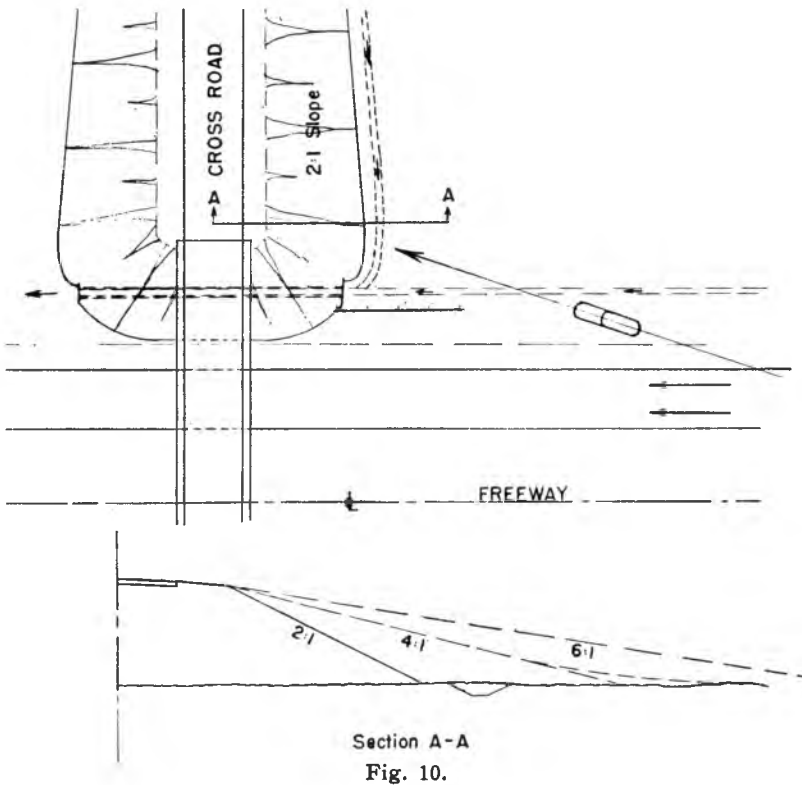


Fig. 9.

Safer Drainage Ditch Design

Fig. 10 shows a freeway separation embankment for a minor cross road. This is quite common on interstate freeways. The embankment is an obstacle that an out-of-control car may hit as shown by the arrow. The cross road itself may be a minor one not justifying flat slopes, etc. In section AA (bottom of Fig. 10), notice that the 2:1 slope and the ditch at the toe of slope can be an appreciable obstacle for an approaching car. The toe-of-slope ditch should be moved to the other side of the embankment, and as shown in dashed lines, the 4:1 and 6:1 slopes are much safer. The curved line at the bottom of the 4:1 slope shows that the rounding would add much safety to that slope. Fig. 10 also shows that the drainage culvert headwall is dangerous. The driver should be protected by a guard rail placed close to the dangerous object. A much better solution would be to place the cross drainage structure further away from the freeway travel lanes.

Fig. 11 shows a private drive with a drainage structure carrying the side ditch thru. We'll assume the side ditch is an easy one with 6:1 slopes. Quite safe as far as the main line cross section is concerned. However, Fig. 11B shows the ditch profile with a standard $1\frac{1}{2}:1$ slope



and the drainage structure with a vertical headwall. This profile is inviting trouble. There is a much better solution shown in Fig. 11C, but it is more expensive. A grated inlet with a 4:1 slope provides a much less hazardous profile. A vehicle can ride up and over with much less chance of a wreck. This solution is not always possible, however. If the pipe is very large, there must be a headwall or end section or something that would still be an obstacle. In that case it is best to protect the driver from the obstacle by a guard rail. Our standards call for 1½:1 slopes for private drives. It was felt that private drives didn't really require flat slopes because of the very few slow vehicles traveling them. However, when the drive is perpendicular to the main line highway, a 1½:1 slope even without any drainage structure can still be a very dangerous object for a high speed vehicle to hit. This 1½:1 slope should be flattened to 4:1 or flatter on the approach side.

Fig. 12 shows a T intersection with a long straight approach to the T. There is a ditch on the far side. It is a rather flat ditch with a not very high back slope, which is 2:1. In Section AA the car going thru

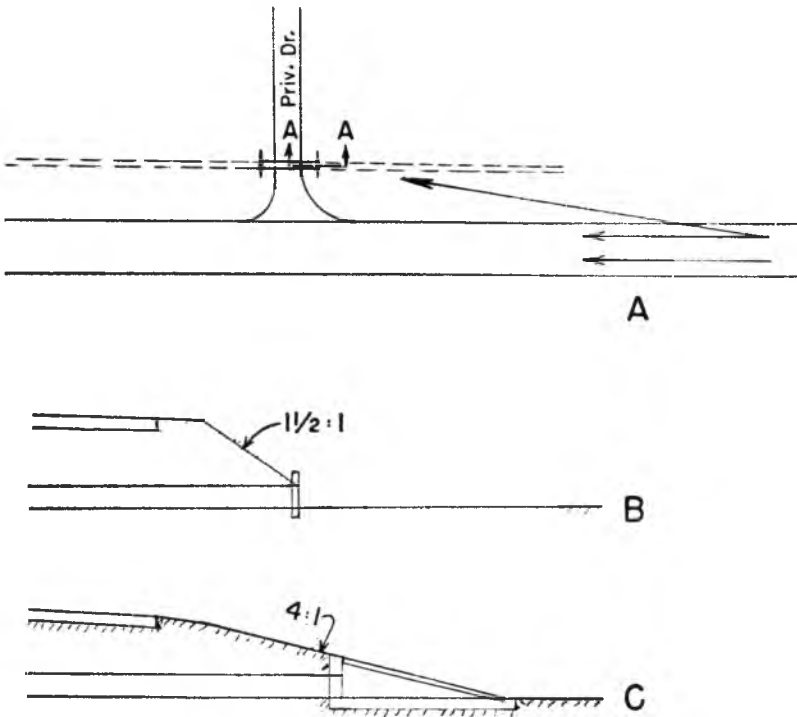
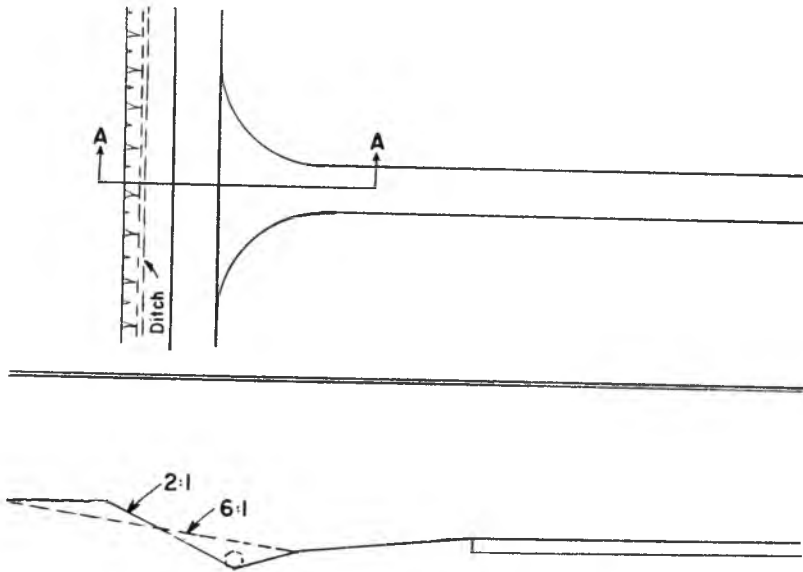


Fig. 11.

the T, and not stopping for it, could get into trouble on this 2:1 back slope. A much better design would be to put a pipe in the ditch and build a 6:1 recovery slope from the shoulder point. A problem such as this with a back slope toe, about two feet higher, than the pavement grade resulted in two fatal accidents. Here we see safety could have been added without the expenditure of many dollars.

GUARD RAIL DESIGN AND PLACEMENT

The designer is faced with placing an obstacle in the path of an out-of-control car. It is quite a compromise with the ideal cross section of no obstacles to hit. However, it is impractical to eliminate all dangerous obstacles, slopes, etc. When this is true, the designer may use the guard rail as the cure. It is not a perfect cure by any means, as there is a definite hazard to crashing into the guard rail. In fact the designer must judge whether the disease is worse than the cure or the cure is worse than the disease. Each time a guard rail is placed, it is likely that there will be some crashes where the driver would have otherwise recovered without hitting the dangerous obstacle, had the guard rail



Section A-A

Fig. 12.

not been placed. The designer needs to place guard rail with the above in mind.

Buried End Guard Rails

Fig. 13 shows some of the newer improvements in guard rail design. First is the buried end. Guard rail must begin somewhere. Burying the end in three panels prevents it from being a spear to the approaching car. On the lower left of Fig. 13 is a cross-section of improved guard rail. It is, however, 2 ft. 7 in. above the ground and is higher by 7 in. than the old guard rail. The beam is attached to posts thru brackets which help absorb some of the impact energy. A channel is added below the beam to prevent vehicles from wedging underneath. Tests have shown these new designs to be better in absorbing impact and in preventing the overturning of vehicles.

Fig. 14 shows alternate aluminum and steel tube types of guard rail. At the present state of knowledge these are considered to be equivalent to the steel beam guard rail. In our plans the contractor is often given a choice of the types of guard rail to be used. Perhaps after we have had some experience with these various new types of guard rail, one type may prove more desirable than the others and be adopted as the sole standard.

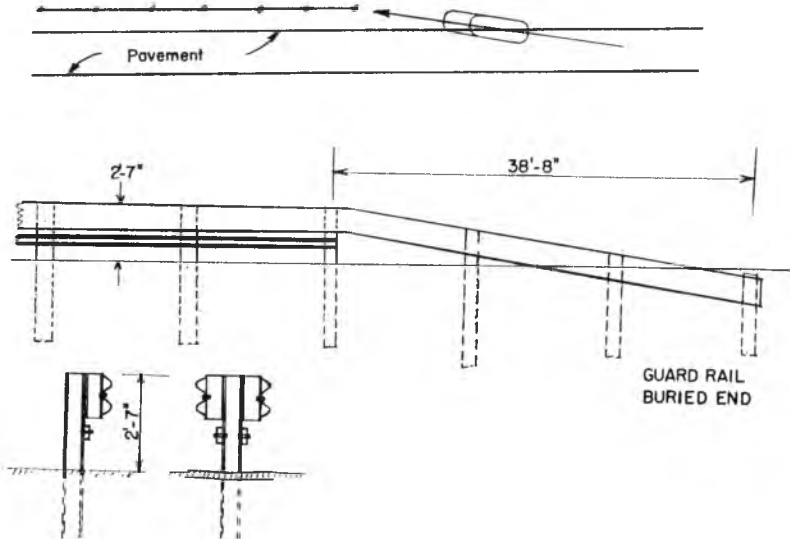


Fig. 13.

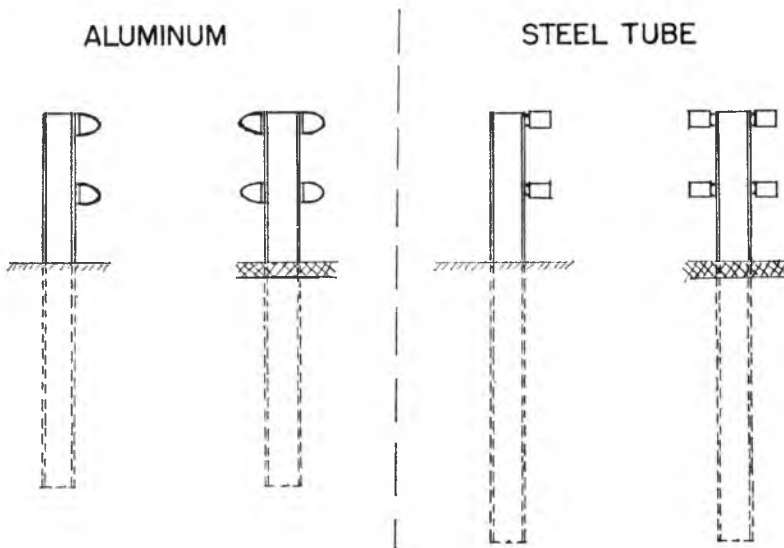


Fig. 14.

Guard Rails at Bridges

Fig. 15 shows standard guard rail protection at bridge piers. It is better design if the outside pier can be eliminated. Then there is much less to hit. Note how there will be some crashes of vehicles that would

not otherwise hit the pier. However, a direct crash into a pier is a very dangerous crash and must be avoided even at the expense of some additional minor crashes into guard rail.

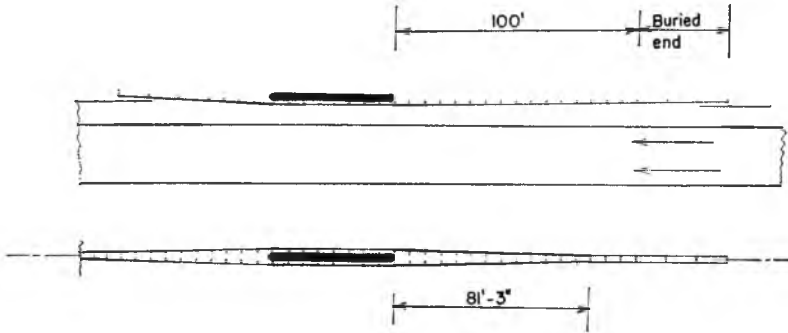


Fig. 15.

Fig. 16 shows guard rail protection at dual lane bridges over streams, railroads or cross roads. The hazards are these: the bridge hand rails on right and left; running down embankments to streams, etc. either to the right or thru the median. These hazards are worse than an angle crash with guard rail. It is now standard to tie the guard rail to the hand rail of the bridge or make it continuous with the bridge hand rail. The aluminum section lends itself particularly to the latter. The dashed line shows a median guard rail location called for on an older standard. However, it was concluded that the guard rail near the opposite lane was doing more harm than good. Sometimes icy bridge floors threw cars out of control toward the median and they would hit the back side of this median guard rail when otherwise the median was considered wide enough to let them recover without being a problem to the opposite lanes.

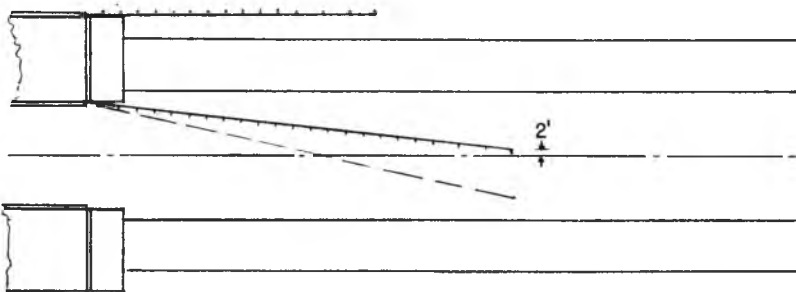


Fig. 16.

Guard Rails at Ramps

Fig. 17 shows guard rail protecting drivers from an obstacle in the gore of a ramp exit. In Fig. 17A it is shown that the impact angles are high. The vehicle going directly toward the object is likely to flip over the guard rail and hit the object anyway. Other vehicles that perhaps would not have hit the obstacle would crash into the guard rail at high impact angles. The designer should always place the guard rail such that the impact angles are most likely to be flat. This is the way guard rail is supposed to operate and is the way it is tested in research. Fig. 17B shows a possible solution. A vehicle heading directly toward the obstacle would ride up on the buried end and probably have its momentum absorbed before reaching the obstacle. Other vehicles that might hit the obstacle are likely to hit the guard rail at a quite flat angle.

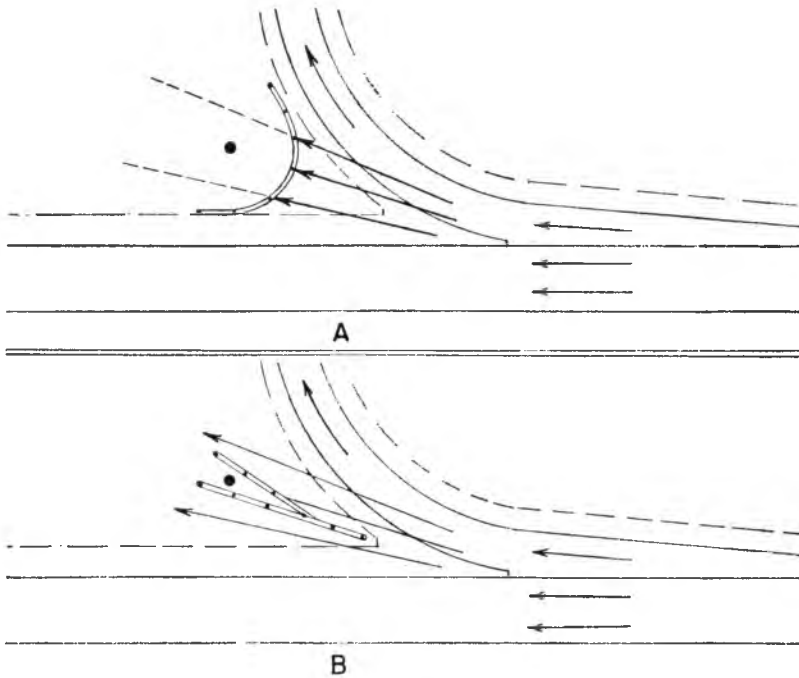


Fig. 17.

Guard Rails in Medians

Fig. 18 shows double faced guard rail in a narrow median. Here guard rail has its strongest safety warrant. Head on collisions of vehicles crossing medians are the worst crashes. The energy absorbing, flat angle impacts with guard rail are far less serious. The double

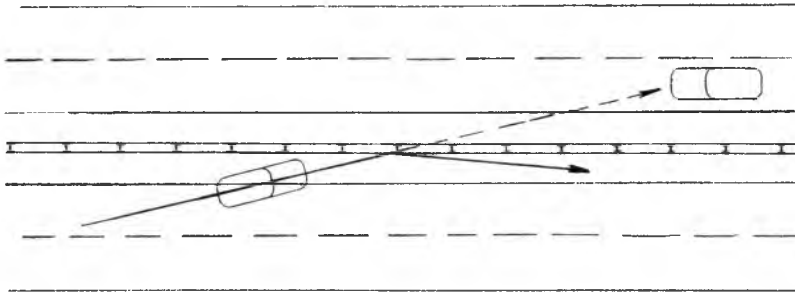


Fig. 18.

faceted guard rail is a much more effective barrier than median curbs and also allows the building of a flush median. An out of control vehicle can easily jump a curb and go right on across and do considerable damage. The trend is to do away with curb medians. With the flush median some of the width may be used as a stabilized shoulder. Also a flush median can store snow.

Barriers for Some Left Turns

One of the major hazards of urban arterial streets is left turning of vehicles. Drivers can dart into quite small openings in the opposing stream sometimes. It is well to eliminate these left turns with the median barrier and allow left turns only at intersections with important cross streets. Both capacity and safety are served with this procedure.

CONCLUSION

The whole field of design for safety has not been completely covered by any means but one designer has presented his approach to the new safety effort as he sees it.