ANALYSIS OF AVAILABLE SIGHT DISTANCES

WITH PROPOSAL OF MEASURES TO ELIMINATE DEFICIENCIES

1. INTRODUCTION

The subject of this Elaborate is an analysis of the available sight distances with a proposal for measures to eliminate deficiencies on the road section Vilusi-Osječenica, approximately ~5.4 km long.

The basis for the realization of this Elaborate was the contract concluded between:

- the Traffic Administration of Republic of Montenegro, as the Client, and
- the design organization, Panpro Team doo from Serbia, as the Executor.

The spatial location of the subject road section is shown on the following picture.

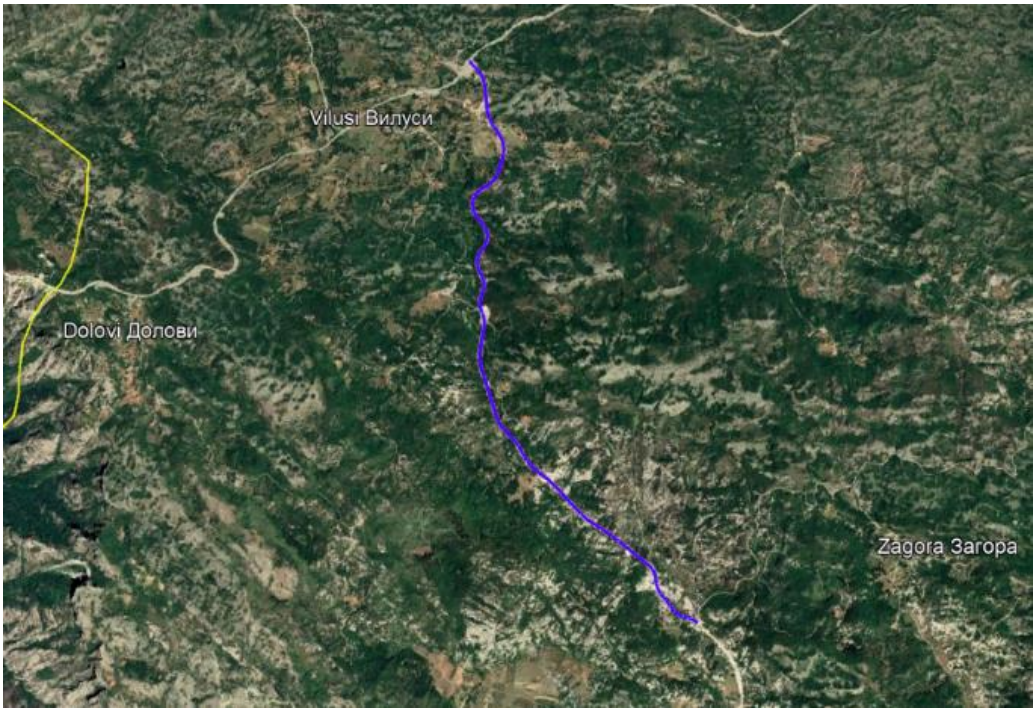

Figure 1. – Spatial layout of subject road section

The images below show the starting and ending points of thesubject road section with their approximate coordinates in the WGS84 system.

Figure 2. – The beginning of the road section in intersection of the state roads M-7 and M-8

Figure 3. – The end of the subject road section

The section in question is located in the western zone of the Municipality of Nikšić and is characterized by a route in hilly-mountainous conditions with a height difference of ~129m and a maximum gradient of ~6.8%. In proportion to the field conditions along the route, the road crossection are changed in the conditions of cuts, cuts and fill, and embankments. Greenery of low to medium density is represented along the route. The population along the subject section is very low.

Since during preparation of this study, there was no reference chainage available, to refer alignment stationing, chainage Km 0+000 was adopted at the beginning of the observed road section, at the intersection of the main roads M-7 and M-8.

With reason to avoid misunderstandings and different interpretation of professional terms used world wide, the terms used in this elaborate are:

- **design speed** = constantly speed used for dimensioning of limitational values of horizontal and vertical elements of road geometry during road designing;
- **operating speed** = variable speed along to road section which should be calculated based on applied/existing road's elements. This type of speed is often equated with 85% having in mind that both of them refer to excpected speed of lonely vehicle on the road;
- **sight distance** = distance from driver's eye to the sudden obstacle measured along the chosen path;
- **line of sight** = line which connect driver's eye with sudden obstacle;
- **required sight distance** = the length of the road between drivers and sudden obstacles necessary for braking and stopping the vehicle;
- **overtaking sight distance** = sight distance necessary for safe overtaking maneuver
- **available sight distance** = the length of the road which is viewable for driver in existing conditions.

2. TERRAIN WORK

Terrain works were carried out on 12.12.2022. and they included recording point clouds with measuring equipment consisting of:

- a lidar (laser) device that records point clouds with a density of 1.3 million points per second;

- an INS (inertial) device connected to GNSS antennas and an RTK modem, whose role is to georeference the points recorded by the lidar device.

The works were carried out in daytime conditions, and considering the period of the year in which the recording was made, it is important to point out that the vegetation was completely without leaves, which in other periods of the year significantly limits the conditions of sight distances.

In addition to recording point clouds along the subject road section, recording was also done with a spherical video camera.

3. OFFICE WORKS

After the completion of terrain work, office work was started, which consisted of the following activities:

- creation of georeferenced point clouds in the WGS84 system;
- projection of georeferenced point clouds in the UTM 34N coordinate system;
- recognition of the road alignment based on 2D position of points within the points cloud;
- recognition of the road profile based on point elevation within the points cloud;
- determining the locations of existing speed limits for both driving directions, based on the established road alignment and information taken from points cloud and spherical video recordings;
- determining locations where overtaking is allowed, according to the same principle as the previous activity;
- creation of a diagrams of existing speed limits along the route, for both driving directions;

- calculation and creation of the operating speed diagrams based on the recognized horizontal and vertical geometry elements of the road;
- creation of a harmonized operating speed diagrams, whereby harmonization refers to the harmonization of the operating speed diagrams with the existing speed limits in junction zones;
- calculation and creation of a diagrams of the required sight distance, for both driving directions, calculated on the basis of the existing speed limits;
- calculation and creation of a diagrams of the required sight distance for both driving directions calculated on the basis of harmonized project speeds;
- determination of available sight distance diagrams for both driving directions;
- visualization of the driver's movements and moving virtual obstacles through a cloud of points by creating appropriate animations for both driving directions;
- analysis of all materials obtained in the previous steps with identification of deficiencies and preparation of proposals for measures to eliminate observed deficiencies.

3.1. Methodological approach to determine the diagrams of available sight distance

Since the available sight distance plays a very important role in the safe traffic flow on a certain road section, as well as considering that this type of sight distance cannot be calculated but must be measured, its measurement was carried out within the scope of this Elaborate by placing a virtual driver in a cloud of points and creating of his pyramids of view.

For the purposes of measuring/determining the available sight distance, for both driving directions, the driver's eye movement paths and virtual obstacles were created, which were defined at a distance of 1.5m from the outer edge of the traffic lane. The height of the driver's eye is defined as 1.1 m above the road. The driver's eye paths, for both driving directions, are divided into 5m steps. At each observed point of movement of the driver's eye, views into the virtual obstacle were created in the form of rectangles (windows) of certain dimensions. A virtual obstacle in the form of a window is placed at a minimum distance of 30m, and then moved in steps of 5m along the path of movement of the obstacle, until sight distance problems are identified.

When the available sight distance for one position is determined, the driver's eye moves to the next position on the path and the process repeats iteratively.

Bearing in mind the previous experience and knowledge in this area when determining/creating the diagram of available sight distance, the entire procedure for any driving direction was repeated with two dimensions of the window, namely:

- 0.1x0.1m, which corresponds to the height of the obstacle as it is it is defined in the valid domain norms of road design;

- 1.75x1.0m, which corresponds to the silhouette of the rear side of the relevant passenger vehicle.

In connection with the previous one, we particularly highlight:

- German guidelines for motorway design, where the height of the obstacle is defined at 1m high;

- the results of the EUsight project (https://www.cedr.eu/call-2013-safety) within which, as a measure to harmonize the different regulations of the EU countries regarding the required sight distance, propose that the height of the obstacle should be 0.4-0.6m;

- the fact that defining the height of the obstacle at 0.1m represents an extremely rigid requirement, in which case any steel protection fence can represent an obstacle to complying with the required sight distance conditions.

Once again, we note that meeting the required sight distance for an obstacle height of 0.1m is an extremely rigid requirement that is almost impossible to comply with. In other words, the satisfaction of that requirement would cause huge construction interventions on the correction of elements of the road alignement and profile. Since Montenegro has not yet adopted the appropriate norms in the field of road design, we suggest that, when adopting those norms, the values proposed by the EUsight project or modeled on German guidelines should be adopted.

In the specific case, since the norms of Montenegro historically rely primarily on the valid norms in the Republic of Serbia, the analysis and proposed measures will be given for alternative values of the height of the obstacle.

3.2. Adopted values and approximations

The following starting values and approximations were adopted for the purposes of making calculations and making different diagrams:

- acceleration coefficient a=0.5 m/sec^2;

- deceleration coefficient d=1.0m/sec^2;

- coefficient of tangential friction ft – variable depending on the speed;

- coefficient of rolling resistance wk=0;

- reaction time t=2 sec;

- longitudinal slope of the road i_N - the value is taken from the tangent polygon of the road longitudinal profile (the influence of vertical curves is ignored);

- safety distance of vehicles ΔL=5m;

- the diagram of permanent speed values for passenger vehicles was not taken into account, since it is very outdated, that is, it does not correspond to the current vehicle caracteristics. Research conducted in Switzerland, at the end of the 20th century, determined that grade gradients of up to 8% have no effect on reducing the speed of passenger vehicles on climbs for speeds up to 80 km/h (http://www.strc.ch/2005/Koy.pdf);

- driver's eye height = 1.1m;

- position of the driver in relation to the outer edge of the traffic lane = 1.5m;

- height of the obstacle = 0.1 m, alternatively = 1.0 m;

- maximum values of operating speed Vp=Vr+20 km/h.

4. SPEED CONTROL - EXISTING CONDITION

The locations of the existing speed limit signs, that have been registered based on the recorded materials are as follows:

Direction: forward	
chainage	**Km/h**
1+099	60
3+143	70
4+711	50

Direction: backward	
chainage	**km/h**
0+144	40
1+098	50
2+267	40
2+999	60
3+142	60
4+714	70

Wherein the last notification about the limited speed for vehicles entering the junction, coming from the Trubjela-Vilusi section, is 50 km/h. That is, the speed limits in different directions on the subject road section are as follows.

Direction: forward		
Beginning chainage	**End chainage**	**Speed [Km/h]**
0+000	1+099	50
1+099	3+143	60
3+143	4+711	70
4+711	5+391.69	50

Direction: backward		
Beginning chainage	**End chainage**	**Speed [Km/h]**
0+144	0+000	40
1+098	0+144	50
2+267	1+098	40
3+142	2+267	60
4+714	3+142	70
5+391.69	4+714	50

Based on the data from the previous tables, it can be concluded that there is a mutual inconsistency of the speed limits in the directions, which is much easier to see by looking at the diagrams given in the graphic attachments. Namely, in the zone of the starting junction, the speed for the forward direction is limited to 50 km/h, while in the opposite direction it is limited to 40 km/h.

The differences in restrictions by direction are even more drastic on the section from km 1+099 to km 2+267. In the forward direction, the limit is 60 km/h, while in the opposite direction it is 40 km/h. The reasons for such a discrepancy are unclear and unjustified.

By looking at the diagram of operating speeds, i.e. harmonized operating speeds, it can be concluded that, observing independently only the horizontal and vertical geometry, the speeds on certain sections may be higher than the limited ones, which is most likely the case with exploitationaly or $V_{85\%}$ speeds. For example, on the section from km 0+324 to km~0+825, the speed could be limited to 70 km/h. Likewise, from km 2+475 to km 4+645, the speed could be limited to 80 km/h in proportion to the existing geometry elements. At the same time, it should bear in mind that the calculation of the maximum permitted operating speed, in this study, is limited to 80 km/h in proportion to the permitted speed that is limited by law on non-urban roads. However, many geometry elements allow movement at speeds over 80 km/h, which is most likely the case with exploitationaly speeds. In the last 400-500m before the end of the road section, speeds could be limited to 60 km/h, not 50 km/h, which is the current limit, according to the diagram of the harmonized project speed.

Speed control has an extremely significant impact on all elements of traffic flow, and, of course, on traffic safety. When managing speeds, it should not be overlooked that irrational and unargued speed limits, lower the service level of the road, do not contribute to traffic safety, and can even be counterproductive.

In any case, proposing corrections in the setting of speed limits, without analyzing the consequences of such measures on the fulfillment of sight distance conditions, is not reasonable and, accordingly, the final proposal will be given after the analysis that will be carried out in the next chapter.

5. SIGHT DISTANCE ANALYSIS

Within the graphic attachments, a diagram of sight distance is shown, which contains:

- diagrams of required sight distance for existing speed limits in both directions;

- diagrams of the required sight distance for the harmonized operating speed;

- diagrams of available sight distance for obstacle height 0.1m and 1.0m;

- values of overtaking sight distance for three different cases of speed ratio V1-V2-V3;

- segments of the subject road section where overtaking is allowed within the current state.

Diagrams of the available sight distance are shown without subsequent corrections, that is, in proportion to the results of the software algorithm and the methodology described in chapter 3.1. The

discontinuities/jumps that appear in the diagrams of the available sight distance are the result of non-continuous disturbances and are most often caused by sporadic disturbances related to vegetation and even to signposts that can represent disturbances for an obstacle height of 0.1m. Since they mostly refer to point disturbances, sporadic jumps/discontinuities in the sight distance diagram can generally be ignored except in the case of their frequency.

5.1. Required sight distance for existing speed limits

By comparing the required sight distance for the existing speed limits in relation to the available sight distance, it can be concluded that it is mostly satisfied, and occasional deviations occur in places where a steel protective fence obstructs sight distance for an obstacle height of 0.1m. However, on some shorter sections, it was observed that problems of not satisfying the required sight distance are also caused by an insufficient berm of visibility in cutting conditions.

Problems with not meeting the required sight distance for the existing speed limits were observed on the following stretches:

- Forward direction

  o km~3+310 - km~3+370 (steel fence)

- Backward direction

  o km~3+650 – km~3+610 (cut).

Sporadic problems with the fulfillment of the required sight distance, for the obstacle height of 0.1m on shorter sections of 10-20m, are ignored in this analysis, because they refer to pointly interference from signposts or sporadic interference from low vegetation along the embankment.

In general, it can be stated that the required sight distance conditions, for the existing speed limits, are satisfactory on the subject road section, for both driving directions.

5.2. Required sight distance for harmonized operating speed

By comparing the required sight distance for the harmonized operating speed in relation to the available sight distance, it can be concluded that there are significant problems on the subject road section. The observed problems are detailed in the following text.

- Forward direction
  - km~0+575 – km~0+635 (cut)
  - km~0+945 – km~1+030 (cut)
  - km~1+615 – km~1+650 (cut)
  - km~1+970 – km~2+000 (cut)
  - km~4+700 – km~4+835 (cut)
- Backward direction
  - km~3+695 – km~3+585 (cut)
  - km~3+280 – km~3+180 (cut)
  - km~2+450 – km~2+420 (vegetation)
  - km~2+315 – km~2+215 (cut + vegetation)
  - km~2+120 – km~2+080 (cut)
  - km~1+960 – km~1+825 (cut + vegetation)
  - km~1+740 – km~1+705 (cut + vegetation)
  - km~1+500 – km~1+235 (cut + vegetation)
  - km~1+145 – km~1+085 (cut)
  - km~0+635 – km~0+525 (cut)

The listed defects refer to the height of the obstacle of 1.0m. If the obstacle height of 0.1m were taken into account, road segments where the required sight distance is not met would be even more pronounced. However, at this point, a stretch from km~3+280 to km~3+370 in the forward direction

should be singled out, where the available sight distance for an obstacle height of 0.1m, in contrast to the available sight distance for an obstacle height of 1.0m, falls below the required sight distance for the harmonized operating speed, and it is a consequence of the interference that the steel fence presents for the lines of sight. Also, in certain cases such as the stretch from km~3+520 to km~3+600 for the forward direction, and the stretch from km~2+625 to km~2+490 for the backward direction, interference with the required sight distance, for the height of the obstacle from 0.1m, represent convex vertical curves whose radius values are close to the limit values, for the harmonized operating speed.

Such cases are particularly pronounced when convex vertical curves are located in conditions of a continuous downhils, because then there is a combination of influence with the gravitational force on the vehicle, which causes longer stopping distances of the vehicle. At the same time, it should be borne in mind that the calculation and creation of the diagram of the required sight distance in the zones of vertical curves is in accordance with professional practice, but it is not theoretically precise because the variability of the slopes along the vertical curve are ignored.

The aforementioned shortcomings and differences in directions are quite logical when you take into account that the segment of the section from km~0+705 to km~2+482 is in a significant rise in the forward direction, i.e. in a decline in the backward direction.

Based on all of the above, it can be concluded that there are significant problems with meeting the required sight distance calculated for the harmonized operating speed, especially in the direction backward where the required sight distance is not met on almost 20% of the length of the subject road section.

The following figure (Figure 4) shows as an illustrated example the zones (circled by elliptical objects) in which exists the problems with meeting the required sight distance. These are the zones in which the values of the corresponding available sight distance for the observed direction, and the corresponding height of the obstacle, fall below the values of the required sight distance.

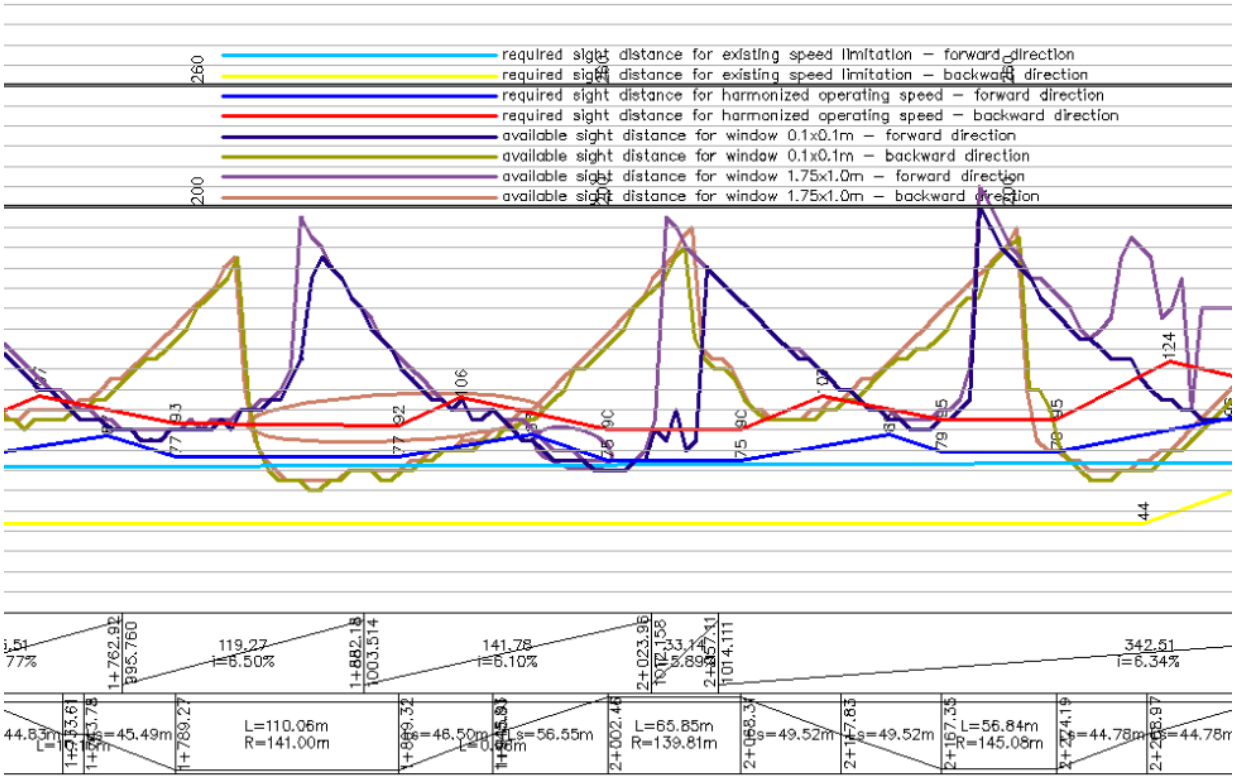

Figure 3. – The example of the road section where required sight distance problems occure

5.3. Overtaking sight distance

On the subject road section, subsections where overtaking is allowed, in the current state, are completely identical for both directions. The tabular arrangement of zones where overtaking is allowed is as follows:

Direction: forward	
Beginning chainage	**End chainage**
0+250	0+385
2+745	3+090
3+205	3+428
3+836	4+087
4+285	4+749

Direction: backward	
Beginning chainage	**End chainage**
0+250	0+385
2+745	3+090
3+205	3+428
3+836	4+087
4+285	4+749

Subsection of the subject section, where overtaking is allowed, are also shown in the sight distance diagram, from where their irregularities can be clearly seen. Namely, it is easy to see from the diagrams, that the zones of available sight distance by direction generally do not match with each other, which indicates that the segments where overtaking is allowed should not match in different directions.

Figure 5, which follows, is highlighted as an example of the non-compliance of the zone where overtaking is allowed with the real state of available sight distance on the spot. In this picture, the zones from km 2+745 to km 3+090 (forward and backward direction) are clearly indicated, where overtaking is allowed within the current state. In the same picture, it is also clearly seen that the diagrams of available sight distance for the observed obstacle height of 1.0m in certain parts of those zones (marked by elliptical objects) fall below the value of overtaking sight distance, even for the speed ratio V1:V2:V3=60:40:60 km/h. The overtaking sight distance for that speed ratio is 200m, where 100m refers to the required overtaking length, and the difference of up to 200m refers to the distance traveled by the oncoming vehicle.

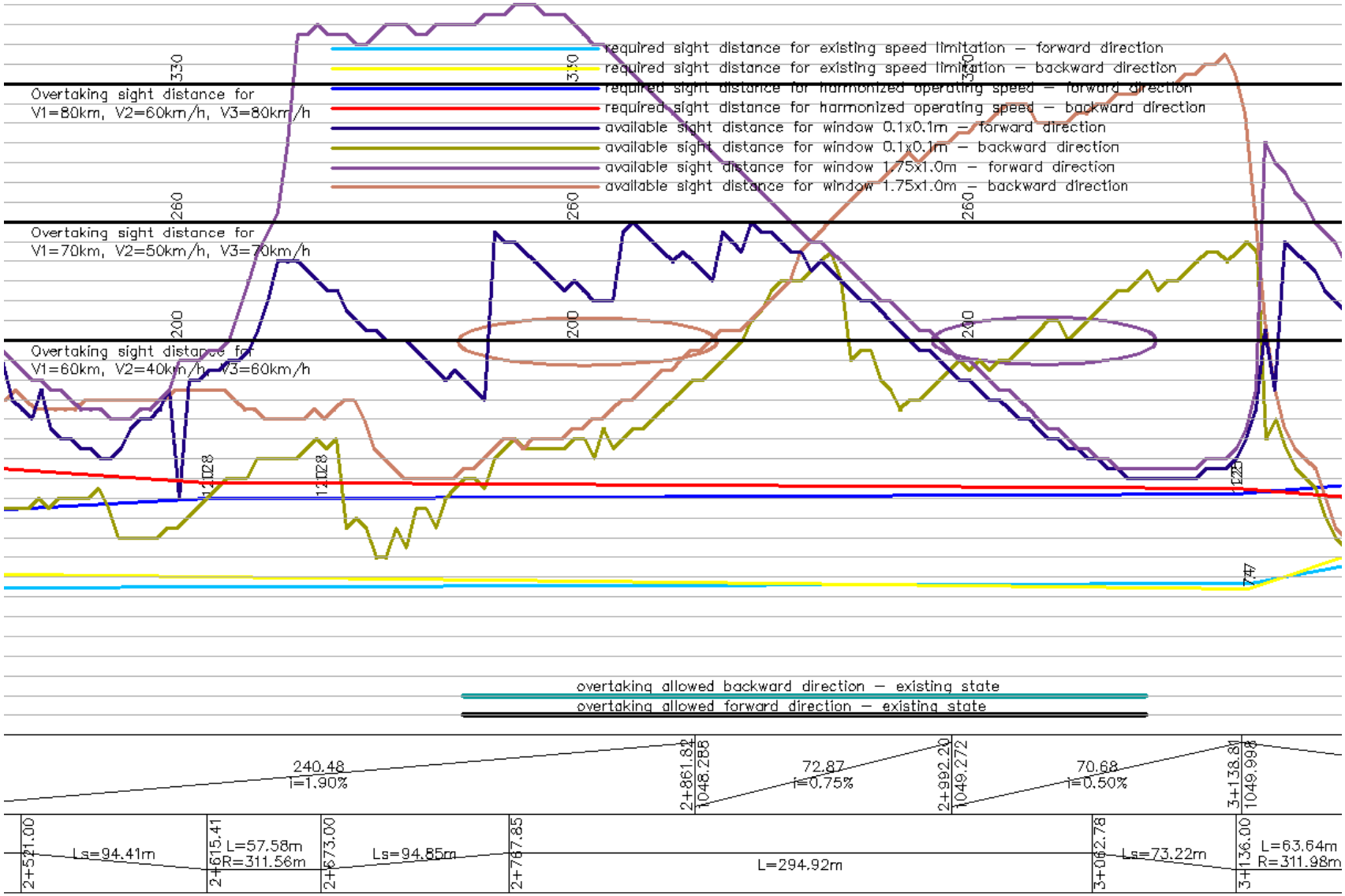

Figure 4. – Example of inconsistency of the zone where overtaking is allowed with the current state of available sight distance

In addition to the segments where overtaking is allowed, the overtaking sight distance values for three different cases of speed ratios V1-V2-V3 are entered in the diagram, where V1 is the speed of the vehicle which performs overtaking, V2 is the speed of the vehicle which is overtook, and V3 is the speed of the oncoming vehicle from the opposite direction.

By looking at the sight distance diagram, it can be concluded that, if the dimensioning of the allowed overtaking zones were based on the case V1=80 km/h, V2=60 Km/h, V3=80 Km/h, the subsections with allowed overtaking would be significantly shortened if conditions of available sight distance do not change.

In addition, if the dimensioning of permitted overtaking zones is based on V1=60 km/h, V2=40 Km/h, V3=60 Km/h, and without changing the conditions of available sight distance, it would be necessary to make the following corrections:

- Allowed overtaking zone from km 0+250 to Km 0+385 is necessary to separate by directions, and into:
    - km~0+190 – km~0+330, for direction forward
    - km~0+360 – km~0+510, for direction backward
- Allowed overtaking zone from from km 2+745 to km 3+090 is necessary to separate by directions, and into:
    - km~2+625 – km~2+985, for direction forward
    - km~2+870 – km~3+150, for direction backward
- Allowed overtaking zone from from km 3+205 to km 3+428 is necessary to correct as follows:
    - withdraw overtaking, for the forward direction, as the stretches where the available sight distance allows overtaking actions to be performed, are not long enough to carry out these maneuvers
    - move the allowed overtaking zone for the direction backward to the section from km~3+375 to km~3+575
- Allowed overtaking zone from from km 3+836 to km 4+087 is necessary to separate by directions, and into:
    - km~3+755 – km~4+030, for direction forward
    - km~3+795 – km~4+185, for direction backward
- Allowed overtaking zone from from km 4+285 to km 4+749 is necessary to separate by directions, and into:
    - km~4+310 – km~4+610, for direction forward
    - km~4+350 – km~4+835, for direction backward

Of course, when determining the zones where overtaking is allowed, it is necessary to take into account other conditions, such as the locations of access roads, etc.

In addition to the above, overtaking, treated only on the basis of sight distance diagrams, could also be allowed on the following segments:

- for direction forward:
    - km~4+120 – km~4+255
- for direction backward:
    - km~0+835 – km~1+060

In general, regarding the existing zones of allowed overtaking and sight distance conditions, it can be stated that there is a significant non-compliance and that corrections need to be made.

Observed in relation to the road design regulations, it can be concluded that the length of the road, on which it is possible to allow overtaking, meets the needs (>20%), and is ~22% for the forward direction, or ~32% for the backward direction.

5.4. Impact of sight distance on speed management

After a detailed analysis of the available sight distance, in relation to the required sight distance, based on the existing speed limits, or on the values of the harmonized operating speed, it can be concluded that there is a discrepancy between the opportunities provided by the geometry elements of the subject road section versus the opportunities provided by the available sight distance. That is, the increase in the permitted speeds on the segments described in point 4., cannot be applied without removing obstacles to the available sight distance, especially in the backward direction. Since the available sight distance in the forward direction does not fall below the value of the required sight distance, for the harmonized operating speed on the stretch from km 2+475 to km 4+645, it can be stated that there is no obstacle for increasing the allowed speed on this stretch and in this direction.

Viewed from the other side, and taking into account the fact that 85% of drivers drive at speeds that are close to the operating speed, it can be stated that significant improvements in traffic safety conditions can only be achieved if problems are eliminated in parts where the available sight distance falls below the required sight distance, calculated for the harmonized operating speed.

At this point, it should be emphasized that measures to eliminate the problem of available sight distance would contribute to better exploitation characteristics, that is, to a higher level of service of the analyzed road section.

6. PROPOSAL FOR SHORT-TERM MEASURES

According to the analysis carried out in chapters 4 and 5, if short-term measures are not possible to expand the visibility berms, in order to improve the available sight distance, the following short-term measures are proposed.

6.1. Correction of the speed limits by direction

Respecting the diagrams of speeds and sight distances, as well as the fact that there is no element of geometry along the route that would limit the speed below the value of the design speed of Vr=60 km/h, the following schedules of speed limits, by direction, are proposed:

Direction: forward		
Beginning chainage	**End chainage**	**Speed [Km/h]**
0+000	0+150	50
0+150	0+970	70
0+970	2+475	60
2+475	4+740	80
4+740	5+350	60
5+350	5+391.69	50

Direction: backward		
Beginning chainage	**End chainage**	**Speed [km/h]**
0+150	0+000	50
1+275	0+150	60
1+470	1+275	50 (60)
1+830	1+470	60
1+915	1+830	50 (60)
2+215	1+915	60
2+290	2+215	50 (60)
2+475	2+290	60
3+135	2+475	80
3+745	3+135	70

4+740	3+745	80
5+350	4+740	60
5+391.69	5+350	50

Essentially, this means that on the sections of the backward direction from km 1+470 to km 1+275, from km 1+915 to km 1+830 and from km 2+290 to km 2+215, it would be necessary, as short-term measure, to widen berms and to remove vegetation that limit the vehicle speed to 50 km/h, which is contrary to the assumed design speed of 60 km/h, contrary to the speeds allowed by the geometry of the route and contrary to the expected vehicles speed on those parts.

6.2. Correction of the zones where overtaking is allowed

It is proposed to apply the measures defined in point 5.3.

6.3. Removal of the vegetation which obstructs sight distance

The following three pictures show an example of how even small bushy vegetation can have a negative impact, i.e. represent an obstacle to visibility.

The first picture shows the road from the driver's perspective. The image is taken from the created animation for the case of moving at a harmonized operating speed and a virtual obstacle height of h=1.0m, placed at the required sight distance. As can be seen from the picture, the yellow cylinder representing the virtual obstacle is hidden, that is, invisible.

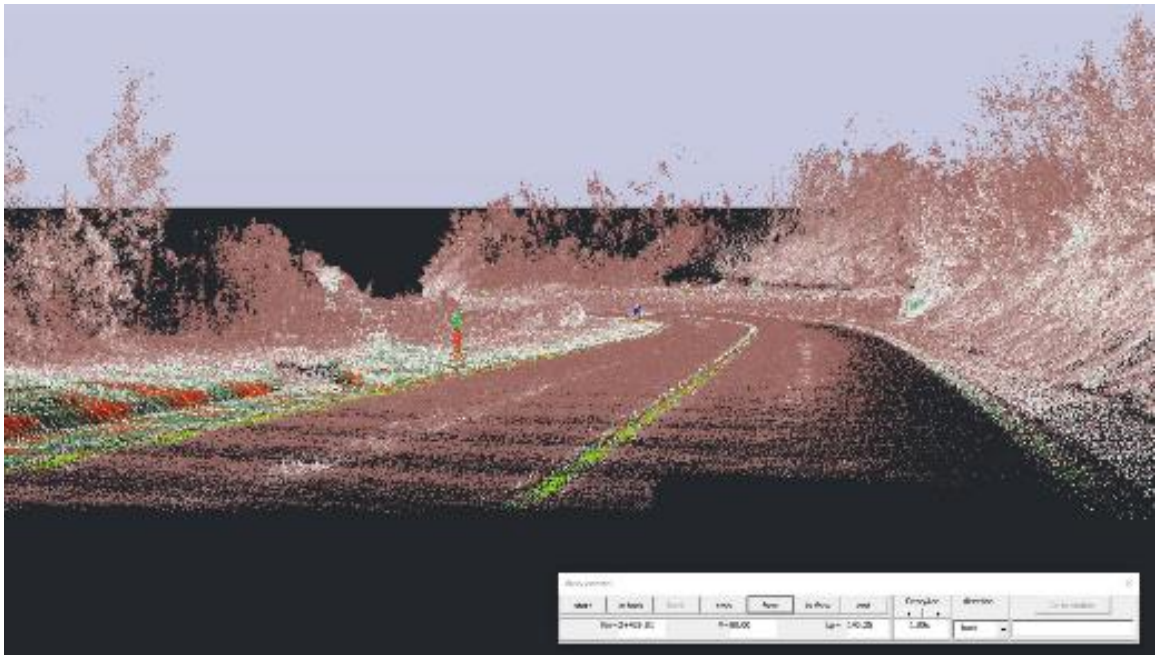

Figure 5. Perspective of the road from the simulation for the harmonized operating speed at the station km~2+440, direction backward

The next picture shows an almost identical perspective obtained from a spherical camera shot, at an almost identical location. In this image, it is almost impossible to detect the low vegetation on the left side of the road in the depth of the image, which obstructs visibility. It is important to point out that, at the location in question, the length of the required sight distance for the value of the harmonized operating speed (V=80km/h) is L_{rsd}~140m, due to the influence of the pronounced negative slope of the road profile. The length of the measured/determined available sight distance, at that specific location, in the direction backward, is L_{asd}~130m.

Figure 7. – Road perspective for chainage km~2+440, direction backward, from spherical camera shot

The following picture shows the small bushy vegetation at km~2+365, which actually, in combination with the elements of the horizontal and vertical geometry of the road, represents an obstacle to visibility.

Slika 6. –An example of bushy low vegetation at km~2+365 on the left side of the road, which, in combination with the elements of the geometry, can represent an obstacle to sight distance

In accordance with the previous, and, considering that the recording was made in winter conditions of vegetation rest, sight distance conditions are much more complicated and complex in the spring-autumn period, so it is extremely important to regularly mow and cut the vegetation along the road.

The strip along the edge of the road, which must be carefully maintained and in which there should be no obstructions to driver's view, is defined graphically by creating three-dimensional lines of sight and their three-dimensional envelope along the road route for both driving directions, based on the diagram of required sight distance.

The lines of sight and their envelopes are necessary to be prepared after the road manager adopts the speed diagram for which the required sight distance must be calculated.

6.4. Correction of horizontal and vertical traffic signalization and equipment

In accordance with the measures proposed in chapters 6.1 and 6.2, it is necessary to create a project for the correction of horizontal and vertical traffic signage.

7. PROPOSAL FOR LONG-TERM MEASURES

7.1. Correction of the speed limit by directions

Based on the comparison of speed and sight distance diagrams, it is easy to determine the inconsistency between the possibilities offered by the geometry of the analyzed road section and the limitations caused by the existing state of the cross profile, road structures and vegetation along the road.

Unlike short-term measures, with the aim of urgently improving of traffic safety conditions, which are mainly limited to changes and corrections of traffic signage and measures of mowing and cutting vegetation, long-term measures mainly refer to the necessary major construction works, which are usually preceded by complex procedures for creating design documentation for enhanced maintenance or road reconstructions that can significantly increase the level of service and traffic safety.

According to the analyzes carried out in chapters 4 and 5, within the framework of long-term measures, it is proposed to harmonize speed management by direction, i.e. to harmonize speed limits with the values of the harmonized operating speed diagram, i.e. the following schedule of speed limits by direction:

Direction: forward		
Beginning chainage	**End chainage**	**Speed [km/h]**
0+000	0+150	50
0+150	0+970	70
0+970	2+475	60
2+475	4+740	80
4+740	5+350	60
5+350	5+391.69	50

Direction: backward		
Beginning chainage	**End chainage**	**Speed [km/h]**
0+150	0+000	50
0+970	0+150	70
2+475	0+970	60
4+740	2+475	80
5+350	4+740	60
5+391.69	5+350	50

Fulfillment of the proposed schedule, would achieve maximum harmonization of expected speeds with speeds that would be limited on the subject road section, and improve operational characteristics (level of service) and traffic safety conditions.

In order to fulfill the proposed schedule of speed limits, it is necessary to create a corresponding diagram of the required sight distance, and expand the visibility berms at all locations along the route of the analyzed road section where the values of the available sight distance fall below the value of the required sight distance.

7.2. Additional analysis

Bearing in mind the very pronounced slope of the road profile from km~0+705 to km~2+480, it is desirable to carry out additional analyzes of the necessity of constructing an additional lane for slow vehicles on the uphill, taking into account, not only the elements of road geometry, but also the elements of the traffic load of the subject road section.

8. CONCLUSION

Based on all of the above, it can be concluded that although the elements of the geometry of the route are in line with the value of the assumed calculation speed Vr=60 km/h, there are a number of problems and deficiencies along the route, that can be classified as influential factors of inadequate speed management and insufficient visibility, which can have significant negative effects on traffic safety. These problems and shortcomings can be classified into the following groups:

- inconsistency of speed limits, by directions;

- inconsistency of the speed limits with the expected 85% or operating speeds;

- the available sight distance values on some shorter segments fall below the required sight distance values:

- the layouts of the road route segments, on which overtaking is allowed, are not in accordance with the restrictions arising from the available sight distance.

Taking into account the requirements of various regulations related to the height of the obstacle, which are listed in chapter 3.1, as well as taking into account the fact that Montenegro has not yet adopted and defined its own regulations in the field of road design, the following recommendations are proposed:

- for the purposes of defining and dimensioning the boundary elements of the road profile, keep the definition of the obstacle height of 0.1m;

- for the purposes of checking the fulfillment of the overtaking sight distance, adopt the obstacle height proposed by the EUsight project or German guidelines;

- for the purposes of checking the fulfillment of required sight distance on multi-lane roads, adopt the height of the obstacle proposed by the EUsight project or German guidelines;

- for the purpose of checking the fulfillment of required sight distance on two-lane roads, especially in difficult mountinious road conditions where rock material is likely to fall and with a transverse profile in conditions of cuts/notches, adopt an obstacle height of 0.1m. An exception to this rule may refer to steel protective fences, whose function is to preserve traffic safety and cannot be avoided on roads. The proposed exception to the rule can also be explained by the fact that the steel fence is placed on the side of the road in the embankment, that is, along the traffic lane that is further away from the slope from which it is possible to spill rock material. In areas where it is impossible to avoid the installation of a protective fence, adhere to the height of the obstacle that applies in the case of overtaking vehicles.

9. COMMENT REGARDING GRAPHIC ATTACHMENTS

The graphic appendices of this report consist of the following parts:

A. Graphic attachments suitable for printing that are formatted in such a way as to be an integral part of the printed version of the report:
- diagrams of existing speed limits and operating speeds;
- diagrams of existing speed limits and harmonized operating speeds;
- sight distance diagrams (stopping, overtaking, available) for different speeds and different obstacle heights.

B. Graphic attachments, animations and video materials that are not suitable for printing and are an integral part of the digital version of the report:
- layout plan with the alignment of the analyzed road section in the georeferenced points cloud (*.dwg);
- longitudinal profile of the analyzed road section (*.dwg);
- georeferenced point cloud in UTM 34N coordinate system, in Autodesk Recap *.rcs, *.rcp format;
- video animations (simulations) of the driver's movement and virtual obstacles at the distance of the required sight distance from the driver, in a cloud of points. The subject animations were created for different cases of speed and obstacle height of 1.0m. Animations for an obstacle height of 0.1m can be created, but due to the small height of the virtual obstacle in question, it is very difficult to recognize them and follow them through the animation;
- a video recording of the section in question taken with a spherical (360°) camera during terrain work;

Prepared by:

Mišel Sabo, dipl. Eng. Civil