Design and construction of site roads

Zlata Dolacek-Alduk1, Sanja Dimter1, Marko Beljan2

1Josip Juraj Strossmayer University of Osijek, Faculty of Civil Engineering and Architecture Osijek, Vladimir Preloga 3, 31000 Osijek, Croatia
2Beljan d.o.o., Rapska 4, 31400 Djakovo, Croatia
zlatad@gfos.hr

Abstract. The purpose of the roads on construction sites, also referred to as site roads, is to enable unobstructed internal transport and timely supply of both the construction site and construction process with materials. They connect storage areas, workshops and plants on the construction site with the place where works on the structure are performed. The quality of site road construction depends on the quantity, type and duration of the traffic they will need to withstand. When solving the issues of internal transport, it is important for the transport to be compatible with construction processes. Transport must be adapted to construction so that it conforms to the necessary dynamics of the construction process. It is possible to determine the trajectories of movement of construction machines and to analyse the swept path of vehicles through the planned routes by using computer programs for analysing horizontal paths of vehicles. The goal of the swept path analysis of construction vehicles is to maintain unobstructed work dynamics. Site roads are built in accordance with legal and technical regulatory requirements in order to enable unhindered internal transport for vehicles on construction sites and safety for people participating in the construction process, as well as to ensure visibility and to preserve the quality and quantity of transported materials needed to build the structure. This paper presents the particularities of designing and construction site roads and describes the process of analysing movement trajectories of the design vehicles on the selected construction sites by using computer programs Autopath 2017 and Autodesk Vehicle Tracking.

1. Introduction

Construction site planning entails organizing the space, equipment and machines needed for the construction process: dimensioning and building of roads and temporary structures on the construction site; dimensioning, designing the layout and building storage areas, workshops, machines, installation schematics etc. [1].

When organizing production processes on a construction site, internal transport needs to be taken into account. Internal transport includes all transportation of materials from the main storage area on the construction site to the location where they are to be used. The main characteristic of internal transport is that it does not increase the value of materials, but rather the expenses of construction, therefore influencing the cost-effectiveness of production. Poorly organized internal transport leads to disruption of the organization of production and any damage of transported materials causes unplanned expenses [2]. The impact of internal transport on organization and costs of construction, potential hindrance of the normal course of action on the construction site, etc. can be analysed, which can significantly rationalize the construction process.
Movement trajectories and swept path of construction vehicles on planned routes on site roads can be tested with computer programs for analysing horizontal paths of vehicles. The goal of swept path analysis of construction vehicles is to maintain unobstructed work dynamics. Advanced computer programs can be used on all construction sites where vehicle manoeuvring around stationary points on the construction site. Those stationary points include the structure being built, vehicle rotation area, loading ramps and storage areas. This paper presents the process of analysing the movement trajectory of design vehicles on selected construction site.

2. Legal and technical regulations for designing site roads

The purpose of site roads is to ensure that internal transport is executed without complications and that the construction site and process are supplied with materials on time. The quality of the construction of these roads depends on the quantity, type and duration of the traffic they will need to withstand [3]. When solving the issues of internal transport, it is important for the transport to be compatible with construction processes.

Site roads are usually built as temporary roads which are removed after construction works are completed. However, it is possible to transform them into permanent roads on the plot where the structure is being built. Generally, the weight of vehicles moving on those roads is greater than those of vehicles moving on public roads, traffic density is lower on site roads and their life cycle is shorter than that of public roads. Therefore, they need to be built with keeping in mind a reasonable proportion of quality and price, and they need to be maintained regularly and removed when construction works are over, i.e. when they lose their purpose.

The moving of vehicles and machines on a construction site is defined within a construction site plan, which is a fundamental part of the construction organization project. Potential problems and points of conflict can be solved by defining the trajectory of vehicles. Such problems can occur within work zones on a construction site or at overlapping points of different work zones, due to the presence of workers moving about on foot, in the vicinity of works and storage areas and due to the mixing of light vehicles with heavy machinery on a construction site. Coarse surfaces, poor visibility and alignment, deep pits and steep banks can also potentially cause problems.

Site roads are built according to legal and technical regulatory requirements in order to enable unhindered internal transport for vehicles on construction sites and safety for people participating in the construction process, as well as to ensure visibility and to preserve the quality and quantity of transported materials needed to build the structure. Out of all valid technical regulations for designing and building site roads, only General Technical Requirements for Road Works (Volumes 1 and 5) clearly specify the rules and procedures for building such roads. According to General Technical Requirements for Road Works, Volume 1 “…access roads and parking lots need to be built according to the construction-management program (CMP), directions given by the supervising engineer or requirements defined in the contract.” Site roads and parking lots must be maintained regularly and it is the contractor’s task to carry out such maintenance (figure 1).

Construction of site roads is conducted within the scope of preliminary work. It entails building, removing, repairing and maintaining of the roads. The cost of building and maintaining site roads, as well as their removal after construction works are completed, is usually included in the total quoted price of construction unless otherwise determined in the construction contract. Such costs belong to a group of indirect costs included in the factor price of the structure; they are not expressed directly as separate items in the quoted bill of quantities.
When establishing a time schedule, the building of roads is planned and presented in the same way as the main construction works. According to [4], the cost of building, maintaining and removing site roads ranges from 6.50 to 12.00 EUR/m². The bulletin Standard Calculation of Building Construction Works [5] estimates that the price of building a road on a building construction site ranges from 4.14 to 11.3 EUR/m². This price includes spreading of gravel in a 20 cm layer, along with levelling and compacting. For the purpose of safe and uninterrupted traffic on access roads leading to the construction site, within the construction site itself and within all plants used during construction work, the contractor is obligated to set up and maintain traffic signs in a required number, form and with technical specifications that are in line with the progress of construction works, as well as with legal requirements prescribed by relevant institutions. As a rule of thumb, vehicles and machines should enter and exit the construction site in the forward direction (instead of reversing). Where necessary, the contractor is obligated to obtain and maintain temporary road lighting. Temporary lighting must provide the same level of lighting as would the public lighting it is replacing. Depending on the size of the construction site, the position of the structure on the plot and the position of connecting roads, traffic on the construction site can be designed to run via a turning circle, a by-pass road or a pass-through road.

According to the General Technical Requirements, Volume 5 [6], in the part describing the construction of road tunnels (Chapter 8-01.1.2 Construction of site roads), site roads are dependent on construction technology selected, on the configuration of the terrain and the construction management design (CMD). They are built by the contractor as temporary roads and maintained by the contractor throughout the realization of the works. These roads mainly connect the places in which construction work take place with the production plants (crushing plant, screening plant, concrete plant, depot of explosive substances, depot of construction materials, laboratory and offices of the project manager, of the supervision staff and the contractor’s administration building). The quality level of the pavement structure and surfacing has to be selected by the contractor depending on construction costs and time needed to complete all works.

Maintenance of site roads, regardless of them being permanent or temporary, must be performed regularly. According to the Ordinance on Road Maintenance [7], regular maintenance of traffic areas that are an integral part of a road includes cleaning and repairing localized damage on roads by patching potholes and cracks, by sanding or performing other similar repairs on the pavement. Considering that temporary site roads are generally constructed from stone surfacing material (crushed stone or gravel), maintenance procedures include patching of potholes, backfilling and profiling, crack repairs, anti-dust
spraying, etc. The aforementioned procedures are defined as the *Ordinance on Road Maintenance* [7], in which the scope and timelines for the works are classified depending on the type of road.

While performing maintenance of traffic areas, the contractor must ensure safe and unhindered traffic and, as a rule, repair any damage on roads by using material equivalent to the one used for the construction of the existent pavement structure. Even roads that are just muddy have an adverse effect due to the decrease of friction and the increase of rolling resistance, which can result in wheel skidding. As an exception, where proper repair is not possible due to exceptionally unfavourable weather conditions or other circumstances, it is allowed to repair the damage by using other suitable materials but just as a temporary solution.

### 3. Guidelines for designing and construction of site roads

In the construction of site roads, one uses guidelines or recommendations acquired based on experience. This is due to the fact that there is a great difference between site roads and public roads, for which there are very clear rules in terms of their design. The fundamental difference can be noted in the speed that different types of vehicles and machines can achieve on the construction site. Speeds on the site depend on the category of the road and on the type of vehicle. In general, these speeds are low \((v=15-20 \text{ km/h})\) because the vehicles on the construction site are heavy goods vehicles (actually medium-heavy or heavy goods vehicles).

Apart from the driving speed, there are several more factors that affect the selection of the horizontal curve radius of the road – construction site structure, road category, type of vehicle and cargo, terrain, intensity and duration of works (table 1). Due to the speeds being too low, the transition lines, functioning as road axis elements, are generally not designed, unless the relevant structure is a permanent site road that will eventually function as a public road and allow higher driving speeds.

| Road category                      | I      | II     | III    |
|------------------------------------|--------|--------|--------|
| Number of motor vehicles per hour  | more than 100 | 15 to 100 | less than 15 |
| **Design speed (km/h)**            |        |        |        |
| For light vehicles and easy terrain| 80     | 60     | 40     |
| For heavy vehicles and medium difficult terrain | 60 | 40 | 30 |
| For heavy vehicles and difficult terrain | 40 | 30 | 20 |
| Roads alongside industrial structures | 40 | 20 | 20 |
| **Site roads**                     | 20     | 15     | 15     |

Vehicle category, dimensions, their overall weight, axle loads, devices and equipment that have to be fitted on the vehicle and the requirements that devices and equipment of a vehicle in traffic have to meet are prescribed under the *Ordinance on Technical Requirements for Vehicles in Road Traffic* [9] and are valid for all types of roads, including site roads.

In addition to maximum vehicle widths, heights, lengths and capacity, the Ordinance regulates that motor and trailer vehicles, as well as combination vehicles, have to be fitted with devices with which, when making a turn, the diameter of the outer circle “drawn” by the wheels shall not exceed 25.00 m while the diameter of the inner circle shall be at least 10.60 m.

Maximum width of a vehicle is 2.55 m, or 2.60 m if it is a refrigerator truck. Therefore, site roads are constructed with a minimum width of 3.0 m. Site roads are usually one-way roads that are 3.0 – 4.0
m wide, while the width of site roads for two-way traffic is between 5.0 – 6.0 m. Overview of basic geometrical characteristics for designing of site roads is presented in table 2.

### Table 2. Overview of basic geometrical characteristics of site roads

| Design speed (km/h) | Road width (m) | Securing of visibility | Cross-slope | Longitudinal slope |
|---------------------|----------------|------------------------|--------------|--------------------|
|                     | One-way traffic | Two-way traffic         |              |                    |
| 15 – 20             | min. 3.0 m      | 5.0 – 6.0 m            | passing places | 2-6%               | 10%                |

Visibility on site roads has to be ensured. On single-track roads, passing places for trucks have to be constructed and their length must be equal to the length of the truck and trailer + 8 m. Passing places are constructed every 300 - 500 m in cases of construction sites for buildings and every 50 - 200 m in cases of civil engineering structures. In addition, the site road has to include a cross drainage solution with a gradient between 2 - 6 % (depending on the type of road surfacing). The longitudinal slope is max. 10% and all vehicles on the construction site must be able to traverse it.

3.1. Swept path analysis for a design vehicle carried out by using the program Autopath 2017

Swept path analysis is an integral part of the design documentation and is implemented by a graphical presentation of the most prominent points of movement of a design vehicle on a bird’s-eye view layout. Nowadays, there is a variety of program packages that make swept path analysis significantly easier and that enable control of the designed solution and timely correction of identified errors. Vehicle database in certain programs is not limited exclusively to cars, trucks and trailers, but it can also be expanded with data on non-standard vehicles such as construction machines, agricultural machines and alike.

An analysis of horizontal machinery transport internal to a construction site is an important part of the construction site management plan. In order to make the implementation of such an analysis possible, it is necessary to define a design vehicle for the site as well as its geometry and accompanying parameters. Based on such specified input data it is possible to make a swept path analysis. A swept path is suitably provided by allowing a width of the running surface that encompasses the surface area within the movement trajectories of the most prominent points in the vehicle’s dimensions, which is then somewhat increased on both sides in order to achieve a safe width. A design vehicle is the vehicle for which it is necessary to ensure a swept path in all allowed directions of movement [10]. For the purpose of static dimensioning of traffic areas, design vehicles are those with the largest dimensions, whereas in terms of dynamic dimensioning, they are the vehicle category that is most common in traffic flow [11]. The Ordinance on Technical Requirements for Vehicles in Road Traffic [9] specifies the maximum vehicle lengths (distance between the most protruding front and rear point of a vehicle (cargo not included) as indicated in table 3.

### Table 3. Maximum allowed vehicle lengths [9]

| Vehicle type                      | Maximum allowed length (m) |
|-----------------------------------|----------------------------|
| Motor vehicles                    | 12.00                      |
| Trailers with drawbars            | 12.00                      |
| **Semi-trailer tractor trucks**   | **16.50**                  |
| **Towing vehicle with trailer**   | **18.75**                  |
| Articulated buses                 | 18.00                      |
| Animal-drawn vehicles, including the cart | 10.00                  |
| Bus with at least 3 axles         | 15.00                      |

Based on the analysis of traffic on the construction site and the analysis of planned internal transport, the conclusion is that the design vehicles on almost every construction site are a semi-trailer tractor truck.
and a towing vehicle with a trailer. Lengths of these vehicles are 16.50 m and 18.75 m, respectively. The dimensions of the aforementioned vehicles also set out the largest space requirements.

Due to the structure of the vehicle itself, towing vehicles with trailers have lower space requirements and required swept path widths [11]. Consequently, the design vehicle for analysis of internal transport on a construction site is the semi-trailer tractor truck with a total length of 16.50 m. For the selected design vehicle, its dimensions and placement of axles are defined according to the allowed axle load and a maximum length of platforms used for transport of cargo (figure 2) [10 – Appendix D].

Figure 2. Position of axles on a tractor truck

Table 4 lists the required swept path widths that are based on the position of the vehicle, as shown in figure 2, whilst driving in a full circle with a different outer radius.

| \( R_1 \) | 12.0 | 12.5 | 15.0 | 17.5 | 20.0 | 22.5 | 25.0 |
|----------|------|------|------|------|------|------|------|
| \( w_v + \Delta w' \) | 10.8 | 9.7  | 7.4  | 6.4  | 5.8  | 5.4  | 5.0  |
| \( R3 \) | 1.2  | 2.8  | 7.6  | 11.1 | 14.2 | 17.1 | 20.0 |

Figure 3 shows the bird’s-eye view layout of the position of the design vehicle (tractor truck) while in motion, with the swept path of the required width [10].

Figure 3. Truck apron width of the central island for the design vehicle

A swept path analysis for the design heavy goods vehicle is shown in figure 4 (marked red in the layout). In the layout, one can see the diagram indicating the wheel rotation of the vehicle, as well as the boundary lines that represent pavement edges. Wheel marks are marked green within the boundary.
lines and, based on this graphical presentation, it is noticeable that the swept path of the design vehicle is suitable for the designed road width and the selected radius of the curve.

Figure 4. Swept path analysis for the design vehicle for an internal road of 4.0 m in width and a horizontal curve radius of R=14.0 m

In case of insufficient pavement width or an unsuitable or small curve radius on the layout, critical points (marked red) will appear on the diagram. This will inform the designer about the necessity of correcting the designed solution.

3.2. Guidelines for construction of site roads

Unpaved (dirt) roads, which are roads without a constructed pavement structure or without the contemporary pavement surfacing. This is the least expensive type of site road construction. However, it also includes great issues in terms of traffic flow when there is heavy precipitation. A site road constructed from natural soil material is constructed under the assumption that vehicles with suitable tyres will move on it. Category II (or category C according to the General Technical Requirements) [12] soils and higher categories are suitable for such roads. Drainage is facilitated if these roads are located on inclined terrain.

Crushed stone or gravel roads are often found on construction sites. They are made by constructing 15 – 20 cm thick unbound base course, made of mixes of gravel and crushed stone laid on previously prepared soil subgrade. Construction of these roads is fast and it is not exceptionally expensive. However, maintenance is expensive. Site roads from backfilled or compacted stone material are mostly meant to be used for shorter periods or for repairing of roads that are in poor condition. Approximately 15 – 20 cm of gravel, crushed stone, sand or waste material obtained from a quarry is backfilled onto the prepared soil. Advantage of such roads is the speed in which they are constructed and their cost-effectiveness. They are of higher quality if their construction is performed by using compaction methods (rollers, compactors). These roads are not suitable for use over longer periods or for heavy loads, due to their expensive maintenance. After some time, they deteriorate so much that they pose a hazard for vehicles, cargo and people, and the driving speed decreases significantly. Stabilized roads are roads constructed by mixing binding materials (lime or cement) with soil, after which they are compacted.
The added binding materials improve soil load bearing capacity and facilitate driving. Selection of binding materials is based on the type of soil. Lime is used to stabilize clayey soils and cement is used to stabilize gravelly and sandy soils. Asphalt and concrete roads are roads constructed with contemporary surfacing. They are used only if it is justified in terms of cost-effectiveness, in cases of long-term use and heavy traffic. The base is usually made from a 10-15 cm thick unbound gravel base course, while the upper asphalt or concrete layer is 4-10 cm thick. Purpose of soil stabilizing is to improve the properties of the soil by increasing cohesion. By adding various binding materials, and by mixing and compacting, soil properties are improved and the soil can withstand larger loads and it also becomes resistant to water penetration. The thickness of stabilized soil is 15-30 cm. Based on the results of soil testing and granulation, there are four procedures used for stabilization: mechanical methods, bitumen, cement and lime. Mechanical stabilization is achieved by adding sand or gravel to the soil. The surface is sprayed with a bitumen emulsion that prevents penetration of surface water or excessive drying out of the processed road section.

Costs of site roads made of concrete are high and they are, therefore, used only in locations with busy traffic that includes heavy vehicles. In cases of soils of up to category III (or category C according to the General Technical Requirements) [12], a gravel or crushed stone base of approximately 20 cm in thickness is required, on top of which one places a concrete plate. Where soil is hard, concrete is placed directly on levelled terrain in the form of a layer of at least 5 cm in thickness. Asphalted site roads are used only in special cases, such as asphalt base traffic surfaces or other production units. The base made from waste stone material or gravel is 10 – 15 cm, and thickness of the asphalt surface is 4 – 10 cm. Aside from the construction of unpaved site roads, prefabricated elements for the construction of temporary roads (like panel-access mats manufactured from high-density polyethylene copolymer) can also be found on the market.

4. Construction of temporary and permanent site roads

Site roads need to be built during the first phase of construction works so that they may be used for transport for the duration of construction, regardless whether these roads are permanent or only temporary, which will be removed once the construction project is completed. When planning site roads, it is necessary to determine whether their location aligns with the location of any future road structures, which would mean that a road could be built immediately, used during the performance of construction works and then, upon completion of the works, it could be remedied to meet the design requirements and kept as a permanent road on the land plot.

Except for the listed standard construction materials, site roads can also be constructed from recycled aggregates. Examples of the aforementioned are the permanent site roads on the locations Sopnica-Jelkovec in Sesvete and Oranice-Špansko in Zagreb [13]. Construction of traffic areas in residential areas Špansko-Oranice in Zagreb and Sopnica-Jelkovec in Sesvete was completed in 2004. Recycled aggregate was obtained by removing existing structures at both locations, after which such aggregate was integrated into unbound base course mixes for site roads. This was also the first application of recycled aggregate for pavement structures in the Republic of Croatia and it was significant because the material was obtained by demolishing existing structures on those same locations. After the works of the demolition of existing facilities of the pig breeding farm Sopnica-Jelkovec and former barracks, Oranice-Špansko were completed, the recovery of material obtained by demolition works was performed. Upon recovery, the material was integrated into permanent site roads (figure 5), specifically, into unbound base courses of future roads in residential areas. Recovery of the material involved crushing, purification and sieving of the material obtained through demolition works (by using crushers, water or air purification devices, separation sieves etc.).
Upon completion of construction of residential areas in the aforementioned locations, the permanent site roads that were used during construction underwent remediation (repair of potholes, levelling and compaction of layers). In addition, testing of achieved compressibility modulus values was performed. Measured values ($M_s = 51 \text{ MN/m}^2$ to $M_s = 88 \text{ MN/m}^2$) were higher than the minimal values of the compressibility modulus $M_s$ required in the design documentation ($M_s = 50 \text{ MN/m}^2$). Unbound base course constructed in such manner was used for adding the asphalt layers (both base and wearing courses) to produce what would be future traffic areas in residential areas in Sesvete and Zagreb. At the location Sopnica-Jelkovec, the volume of recycled material obtained from demolition works and integrated into permanent site roads was 19,000.00 m$^3$ and at the location Oranice-Spansko it was 11,000.00 m$^3$.

5. Conclusion

Development of technology and the possibilities offered by various program packages provide us with the possibility of faster and simpler control of all designed solutions for temporary site roads that are an integral part of the construction site management plan. It is important to note that the rules applicable to the design of temporary site roads used for internal transport are equivalent to the rules applicable to public road design. This indicates the level of importance of temporary roads for each construction site, as well their importance as a part of the construction site management plan. A properly constructed and well-maintained site road enables higher driving speed, fewer standstills or vehicle breakdowns and less damage to cargo.

References

[1] A. Pem, L. Malyusz, “Arrangement of material depots for line segment – modeled structures using continuous conditions”, *Organization, Technology and Management in Construction*, Vol. 8 No. 1, pp. 72-80, 2016.
[2] V. Simovic, “Leksikon gradevinarstva“, Masmedia, Zagreb, 2002 (in Croatian).
[3] M. Radujkovic i suradnici, “Organizacija gradenja“, University of Zagreb Faculty of Civil Engineering, Zagreb, 2015 (in Croatian).
[4] S. Harms, D.G. Mans, O.G. Schepers, U.F.A. Karim, „Design method for temporary roads at residential construction site in the Netherlands“ in Eren, O.; Mohamed, A.; Gunyakti, A.; Soyer, E.; Bilsel, H. and Kunt, M. M. (Ed.) *Proceedings 8th International Congress on Advances in Civil Engineering (ACE2008)*, Eastern Mediterranean University Press, Famagusta, North Cyprus, pp. 3-10, 2008.
[5] Standardna kalkulacija radova u visokogradnji, Croatian Institute of Civil Engineering, Zagreb, 2015 (in Croatian).
[6] P. Dukan, and Z. Tomljanovic, Opci tehnicki uvjeti za radove na cestama, Book 5: Road tunnels,
Croatian roads - Croatian highways, Zagreb, 2001 (in Croatian).

[7] Ordinance on Road Maintenance (Official Gazette 90/14), Ministry of Maritime Affairs, Transport and Infrastructure, 2014 (in Croatian).

[8] J. Klepac, „Organizacija gradenja - Uredenje gradilista“, Civil Engineering Institute, Faculty of Civil Engineering, University of Zagreb, Zagreb, 1982 (in Croatian).

[9] Ordinance on Technical Requirements for Vehicles in Road Traffic (Official Gazette 85/16), Ministry of Maritime Affairs, Transport and Infrastructure, 2016 (in Croatian).

[10] T. Cvetko, Smjernice za projektiranje kružnih raskrižja na državnim cestama, Croatian roads, 2014 (in Croatian).

[11] I. Legac i koautori, “Gradske prometnice”, University of Zagreb, Faculty of Transport and Traffic Sciences, Zagreb, 2011 (in Croatian).

[12] Opći tehnički uvjeti za radove na cestama, Book 1: General provisions and preparatory works, Croatian roads - Croatian motorways, Zagreb, 2001 (in Croatian).

[13] A. Stanic, and S. Dimter, „Application of Recycled Aggregates in Pavement Base Courses“, in Lakusici, S. (Ed.) Proceedings of the First International Conference Road and Rail Infrastructure - CETRA 2010, Department of Transportation, Faculty of Civil Engineering, University of Zagreb, pp. 291-297, 2010.