Safe Operation of All-Wheel Drive Articulated Dump Trucks on Large Slopes in Deep Open-Pit Mines

A V Glebov

Candidate of Engineering Sciences, Deputy director on scientific questions, Federal state budget establishment the Institute of Mining, Ural branch of Russian Academy of Sciences (IM UB RAS), Russia, 620075, Ekaterinburg, 58 Mamina-Sibiryaka st.

E-mail: glebov@igduran.ru

Abstract. The analysis have been carried out for the production of all-wheel drive articulated dump trucks. The practical experience of operation of dump trucks as open-pit transport has been analyzed. The paper describes the technical characteristics of some models of articulated dump trucks of Russian and Belarusian production. The paper describes the examples of transportation of rock mass at enterprises of Russia and abroad. The paper points up the special aspects for making the organizational, technological and design decisions in the implementation of articulated dump trucks. The paper shows the experience of operation of all-wheel drive articulated dump trucks in open-pit mining. It has been established that articulated dump trucks allow to increase the efficiency of mine development at the stage of construction and commissioning of mining and processing plants, especially in geographically remote and inaccessible territories. The measures have been developed for safe operation of all-wheel drive articulated dump trucks in open-pit mining at the development of deep-seated mineral deposits. To implement the program of import substitution of all-wheel drive articulated dump trucks it is necessary to perform market research to study the possible market of consumption of vehicles of this class at open-pit mining operations in order to justify the prospects for provision of the Russian production market.

1. Introduction

In the world the ADTs are produced by Volvo, Caterpillar, Bell, Liebherr, Komatsu, Mitsubishi, Terex, BELAZ-HOLDING (see Appendix).

In Russia, the production of the ADTs is just beginning. In Cheboksary in 2013 the plant JSC Promtractor of Concern Tractor Plants had assembled the first dump truck C-33 (Concept) with a capacity of 33.5 tons, having the possibility of turning by 45° in each direction. The maximum speed reaches 57 km/h. The dumping angle is 72°. The dump truck Cummins QSX15 has a rated engine power 336 kW (457 hp) [1].

ZAO Zavod Specmachine has presented the three-axle articulated dump truck with a capacity 25 tons with a wheel configuration 6×6 with self-locking differentials and hub reduction axles. The dump truck is equipped with an eight-cylinder V-shaped engine and 24-speed hydromechanical transmission [2].

In 2014 Saint-Petersburg's Tractor Plant had presented to the public the two-axle all-wheel drive dump truck K-708.2 with a capacity 20 tons. The modified sample K-708.2 has a capacity 25 tons. It
has a 300 horse power Cummins engine and ZF transmission. Suspension is rigid and unsprung. Steering column is with tilt adjustment [3].

Belarusian manufacturers also did not ignore the segment of articulated dump trucks. Technical characteristics of some models of ADTs of Russian and Belarusian production are given in Table 1.

2. Experience of operation of articulated dump trucks in mine development

The ADTs have proven themselves in various sectors of construction while transporting the cargoes in difficult conditions, as well as while extracting the minerals and building materials in the open-pit mines to transport them from the mine faces to the unloading points.

Positive world experience for operating the dump trucks Volvo A40D at the enterprises Marmi di Carrara Srl (Carrara, Italy) and WBB Minerals for the extraction of plastic clay (England) and the dump trucks SAT-740 at the open-pit mine Tarmac Pant Quarry (Wales, England) allow us to conclude about reliability and quality of these vehicles [4].

Table 1. Technical characteristics of articulated dump trucks of Russian and Belarusian production.

| Index                          | Unit       | Russia          | Belarus         |
|-------------------------------|------------|-----------------|-----------------|
|                               | C-33 Concept | 709TSh Baltiets | Kirovets        |
| Wheel configuration           | -          | 6x6             | 4x4             |
| Capacity                       | t          | 33.5            | 25              |
| Engine                         | Cummins QSX15-C336 | n/a        | Cummins QSB6.7  |
| Power                          | kW         | 336             | 194             |
| Possible slope degree          |            | 36              | 20              |
| Body capacity:                 |            |                 |                 |
| Geometrical body capacity      | m³         | 16              | 12              |
| Piled                          | m³         | 20.5            | 14              |
| Radius of turning              | m          | 9               | 9.4             |
| Weight without load           | t          | 29.1            | 16.5            |

In the open-pit mine Tarmac Pant Quarry for the extraction of 1.2 million tons/year of limestone the dump trucks Cat-740 with a capacity 38 tons deliver the rock mass to the open pit wall, where it is loaded into a mobile crusher and stored in a stack by a conveyor, from where it is conveyed for further processing. The total lifting height is 100 m, the length of the slope is about 800 m with an average slope of 12.5 %, with a variation of the longitudinal slope of individual sections of the route from 10 to 26 %.

The mining company Marmi di Carrara Srl, developing the marble deposit in a open-pit mine, uses Volvo A40D with a one way traffic for cargo and empty routes. Two vehicles of this class carry 2000 tons/day of rock mass. The maximum slope angle is 35 %. According to employees (engineers and drivers) [5], the engine brake completely allows you to control the driveway of the dump truck on the slope, eliminating the need for the use of service brakes.

In Russia, the ADTs are used by oil and gas producing companies, developing the deposits in difficult climatic and off-road conditions. As well as abroad at open pit mining the ADTs are used mainly in the production of building materials: marble slabs, rubble, clay, etc.
One of the examples of the operation of the ADTs at the open-pit mines of the Russia's iron ore industry is the plant Magnesite, which currently operates 10 dump trucks Bell B40D [6], which have operated by 12,000÷14,000 machine hours, one dump truck Bell B50D and 6 dump trucks Volvo A40F. During 6 months of operation of the dump truck Bell B50D, its operating time was more than 2,500 machine hours. All this period the dump truck worked in the most difficult mining and geological conditions associated with the transportation of rocks on routes with slopes up to 15%., clay base and height differences up to 190-200 meters at relatively short transport distances.

In 2011, the construction of the mining and processing plant and the preparation of the diamond deposit named after V. Grib for mining [7]. Industrial deposit development is carried out in deserted areas, in heavily watered and wetland areas, in harsh climatic conditions of the European north of Russia. All technological cargo transportation in the open-pit mine is carried out by road transport. Due to the low bearing capacity of rocks for the initial period of opening and preparation of the deposit for exploitation, quite common in small and shallow open-pit mines of Russia it is customary to use the mine dump trucks BELAZ-75473 with a capacity of 45 tons and cross-country articulated dump trucks BELAZ-75281 with a wheel configuration 6×6 and a capacity of 36 tons.

Safety of operation
Measures to ensure safe operation of the ADTs on steep slopes are shown in Table 2.

1. When operating the ADTs the enterprises should be guided by general safety requirements when working on motor vehicles [8], “Uniform safety rules at open pit mining” [9], “Rules for the design and safe operation of pressure vessels” [10].

2. It is necessary to comply with the manufacturers' safety requirements and warnings related to the design of dump trucks and delivered to consumers (customers) in the form of instructions or manuals in the equipment's technical documentation kit.

| Emergency situation                      | Possible causes       | Probability of situation during the day, %, (at run up to 100 km) | Estimated impact of situation | Measures to exclude severe consequences                                      |
|------------------------------------------|-----------------------|---------------------------------------------------------------|-------------------------------|--------------------------------------------------------------------------------|
| Fault of the service braking circuit.    | Sudden failure.       | 0.7-1.2                                                       | Dump truck may roll down at unexpected stop on slope etc. | Timely use of all other methods of braking the dump truck. (To be guided by the operating instructions). |
| Failure of both service braking circuits. | Sudden failure.       | 0.3-0.5                                                       | -                             | Timely use of all other braking methods, controlled movement until the absorbing buffer and stopping at ramp, timely maintenance and repair. |
| Failure of engine or its external systems; accidental stopping of engine. | Failure of any unit; incorrect drive. | 0.8-1.5                                                       | Dump truck may move downhill after its stopping and related cases. | Timely use of braking systems, high qualification of drivers, timely maintenance and repair. |
### Emergency situation

| Emergency situation | Possible causes | Probability of situation during the day, %, (at run up to 100 km) | Estimated impact of situation | Measures to exclude severe consequences |
|---------------------|-----------------|---------------------------------------------------------------|--------------------------------|----------------------------------------|
| Spin skidding of dump truck. | Low coefficient of friction due to icy condition, relatively thick layer of dirt on the road; inattention of the driver, ineffective action of brakes, weak pressure in any tire wheels, etc. | - | Crossing into oncoming traffic; turning of dump truck across the road; it may collide with another vehicle. | Control of sufficient coefficient of friction for safe movement; high qualification of drivers; organization of movement of vehicles during transitional periods of the year. |
| Coming off the transport berm. | Uncontrolled movement of dump truck on slope due to failure of control systems; poor visibility or other reasons. | Very rarely. | Drop of dump truck down to lower bench (horizon). | Road barrier according to the Construction Directives and Rules as well as recommendations. |
| Crossing into oncoming traffic. | Inattention of the driver, poor visibility, spin skidding, failure of steering, rocks on driving lane. | - | 1. Collision with oncoming dump truck. 2. Coming off the berm. | Organization of one-way traffic. Installation of median barriers. High qualification of drivers. Compliance with traffic rules. |

3. In order to avoid fire on the dump truck, it is necessary to comply with the general fire safety regulations for handling the combustible substances and to comply with the manufacturer's recommended requirements.

4. In order to avoid emergency situations, it is necessary to comply with the regulations of maintenance and repair recommended by the manufacturer, as well as to use original spare parts, components and consumables.

5. The design safety of the dump trucks shall comply with international requirements for Rollover Protective Structures (ROPS), Falling Objects Protective Structures (FOPS) and/or Tip-Over Protective Structures (TOPS).

### 3. Arrangement of ramps

1. Operation of the ADTs on steep slopes is allowed on roads constructed subject to geometric dimensions and operational parameters of the dump trucks corresponding to the Construction Directives and Rules 2.05.07 — 91* [4]. When operating the ADTs of different manufacturers and different geometrical dimensions, the width of the roadway and the transport berm is determined for the dump truck with maximum overall width. The minimum width of the roadway is 10.8 m, and that of the transport berm is 19.6 m.

The use of wider dump trucks requires to refine the width of the roadway and the transport berm.
2. At the transport berm lane on the side of the mined-out space, it is necessary to arrange the median barriers in the form of windrow or crest (pillar) left during formation of transport berm or reinforced concrete structures with anchor fastening.

For the ADTs with a capacity 37-40 t the height of the median barriers should be at least 1.5 m.

3. Roads in operation shall be maintained in a condition that provides the necessary tire-to-surface friction coefficients to realize the towing capacities for driving the dump trucks or to keep them on a slope in the event of unforeseen stopping.

For the ADTs the calculated coefficient of friction with dry ground surface of the road at the slope of the ramp up to 350‰ shall be not less than 0.3.

4. At curved sections of transport berms it is necessary to provide the roadway widening (see Table 3).

| Road curvature radius, m | Length of ADT, m |
|------------------------|-----------------|
|                        | Caterpillar 740 | Volvo 40D | Hitachi AN400 | TerexTA40 | Komatsu HM400 |
| 20                     | 10.89           | 11.287     | 10.664       | 10.944     | 11.025       |
| 30                     | 0.274           | 0.284      | 0.268        | 0.275      | 0.278        |
| 40                     | 0.136           | 0.141      | 0.134        | 0.137      | 0.138        |
| 50                     | 0.109           | 0.113      | 0.107        | 0.110      | 0.110        |
| 60                     | 0.091           | 0.094      | 0.089        | 0.091      | 0.092        |
| 70                     | 0.078           | 0.081      | 0.076        | 0.078      | 0.079        |
| 80                     | 0.068           | 0.071      | 0.067        | 0.068      | 0.069        |
| 90                     | 0.061           | 0.063      | 0.059        | 0.061      | 0.061        |
| 100                    | 0.054           | 0.056      | 0.053        | 0.055      | 0.055        |
| 150                    | 0.036           | 0.038      | 0.036        | 0.036      | 0.037        |
| 200                    | 0.027           | 0.028      | 0.027        | 0.027      | 0.028        |

5. The confined spaces during the completion of the open-pit mine allow two-way traffic of the ADTs.

6. On two-way roads it is necessary to establish a median. The median may be marked by appropriate road signs to ensure their visibility at night and in conditions of poor visibility and by other means, which are not contrary to the safe operation of dump trucks.

7. The long ramps should be equipped with absorbing buffer systems with a length of not less than 50 m with a slope of not more than 5% every 90-100 m of lifting.

Driving on steep slopes

1. The maximum speed of movement of the loaded ADT on steeply inclined ramps: is limited for uphill to the towing performance of the propulsion system, but cannot be more than 10 km/h; it being limited for downhill to the retarder performance, but cannot be more than 15 km/h.

   The maximum speed of the unloaded ADT downhill and uphill is not more than 15 km/h.

2. Abrupt movement and braking at curves and slopes are prohibited. Overtaking of dump trucks in any direction is prohibited.

3. Driving of the loaded ADT downhill by the ramps with a slope of more than 180‰ is allowed only at a distance of transportation not more than 200 m.

4. On the section of simultaneous presence of oncoming dump trucks at a steep ramp, the speed of the unloaded dump truck should be reduced to 3÷5 km/h until the loaded dump truck passes by it.

4. Face work and handling work

1. Driving of the ADT downhill to the open-pit mine face by steep slope should be made forward. Maneuvers for spotting the dump truck when passing the ramp are carried out on the site with a slope of
not more than 80÷100‰ and a length of not less than 50 m and prepared by the excavator and/or bull-dozer.

In manoeuvres on the berm, the distance from the extreme point of the dump truck to the upper and lower edge of the bench shall be at least 1 meter. The meter-wide zone along the bench edge of the mined-out space located at the area of manoeuvres of dump trucks during spotting shall be marked by warning signs (e.g. STOP) with a distance of 10 m from each other.

2. The dump truck shall be loaded as required by the manufacturer (side or rear), and the excavator bucket shall not be moved over the driver’s cab. The distribution of the rock mass in the dump body should be uniform according to the certificate of loading.

3. Loaders with a bucket capacity of not more than 8 m³ shall be used when loading the ADTs with a capacity of 37÷40 t. It is prohibited to exceed the rated capacity of the dump truck.

4. It is not recommended to load oversize material (a piece exceeding the permissible mass) into a dump truck. Transportation of oversized pieces of rock mass should be carried out by dump trucks (building stone trucks) equipped with special bodies. In the absence of a building stone truck at the enterprise it is allowed to transport oversize material by a dump truck with a conventional body. At the same time, the loading of oversized pieces should be carried out on a “cushion” formed from fine fraction of the rock mass.

5. Reversing manoeuvres in the truck area are permitted when the dump truck is equipped with an audible signal and/or a rearview camera with a monitor in the operator’s cab.

6. Unloading of the ADTs on a steep slope is prohibited.

7. Unloading at waste dump or reloading point is permitted only after the dump truck has been placed in the position of straight movement. Unloading of several dump trucks at the same time is permitted provided that the safety distance between them being not less than 2 m.

8. Unloading and loading of dump trucks is permitted only when the parking and auxiliary brakes are switched on.

9. In the unloading zone for the bench a bulwark of not less than 0.5 the wheel diameter shall be formed on the edge. Unloading for a bench without a safety bulkwark is prohibited.

10. It is not allowed to move from a standstill when the platform is raised. After unloading, lower the platform and only after that start moving.

11. Do not leave the cab when lowering or lifting the platform. When lifting the platform, you cannot stand near the dump truck to avoid injury by the ground remaining in the platform.

5. Weather conditions

1. When visibility is less than 50 m in the case of fog, snow and/or gas pollution, the movement of the dump truck on a steeply inclined ramp is prohibited.

2. During temperature changes, as well as in winter, the roads should be systematically cleaned of snow, ice and sprinkled with sand, slag, fine crushed stone or treated with special composition.

3. Under icy condition of roads, the movement of the dump truck on a steeply inclined ramp is prohibited. The resumption of traffic is allowed after the proper treatment of the road pavement.

6. Towing of ADT

1. In case of forced stopping of the dump truck on a slope, it is necessary to take measures to prevent its spontaneous movement: brake by the parking brake system, stop the engine, put the wheel chocks under the wheels and wait for the towing vehicle.

2. It should be remembered that braking of the stopped dump truck by activating the hydromechanical transmission step is impossible, because when the engine is idle, the connection between the driving wheels and the engine is missing.

3. The towing of a broken dump truck is carried out only by means of a rigid coupling.

4. The towing is permitted by two dump trucks of the same class as the towed dump truck, and these trucks being located fore and aft the towed dump truck.
5. When towing a broken dump truck with only one vehicle (wheeled or tracked), the towing vehicle should be of heavier class. In this case, the strength of the rigid beam shall not be less than 150% of the total mass of the towed vehicle.

6. The speed of towing the ADT with the engine-off is not more than 2 km/h.

7. References

[1] 2013 Events: new machinery of JSC Promtractor — articulated dump truck C-33 Access mode: URL: http://promtractor.tplants.com/en/events/news/2013/05/28/

[2] 2011 Mine dump trucks Baltiets will compete with BelAZ Access mode: URL: http://www.zavodsm.ru/novosti/i/karernie-samosvali-baltiets-sostavyat-konkurentsii-belazam/

[3] 2017 Kirovets K-708.2 Access mode: URL: http://kirovets-ptz.com/rus/catitem/52/DilerAccount

[4] 2007 Articulated dump trucks Volvo. Experience of exploitation (deposits in Italy, England, Norway, Russia) LLC TLK Gross — Volvo CE dealer

[5] 2012 Presentation of BELL B50D Access mode: URL: http://www.gross-ce.ru/news.php?id=31

[6] Zaostrovtsyev V I, Yapprov Ya A, Klimenko Ya A and Nalivayko V A 2014 The first stage of development of deposit named for Grib V, preparatory and capital mining operations J. Gorny zhurnal 3 48

[7] General safety requirements when working on motor vehicles

[8] 2003 Uniform safety rules at open pit mining. PB 03-498-02 (Moscow: Gosgortekhnadzor of Russia) p 145

[9] 2003 Rules for the design and safe operation of pressure vessels PB 03-576-03 (Moscow: Gosgortekhnadzor of Russia) p 137

[10] 1996 Industrial transport. construction directives and rules 2.05.07 — 91* (Moscow: Ministry of Construction of Russia) p 112

[11] 1986 Norms of technological design of mining enterprises of non-ferrous metallurgy with open pit mining of VNTP 35 — 86 (Moscow: Mintsvetmet USSR) p 109