COMPOSITE : JOURNAL OF CIVIL ENGINEERING
UNIVERSITAS MERDEKA MALANG

ISSN-P : 2964-6626 ISSN-E : 2961-7111

▪ Construction Engineering ▪ Transportation Engineering ▪ Water Engineering ▪ Environmental Engineering ▪ Construction Management ▪ Geotechnical Engineering ▪ Occupational Health and Safety in Construction ▪ Construction and Environment Law.

COMPOSITE : JOURNAL OF CIVIL ENGINEERING
2024. Vol. 03. Number. 01 : 1-12

Available (PDF) : https://jurnal.unmer.ac.id/index.php/jtsc

Analysis of Heavy Equipment Productivity in the Solo – Yogyakarta – NYIA Kulon Progo Toll Road Construction Project Section 1 Package 1.1

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Keywods :
Duration; Productivity; Heavy equipment.

Abstract
The Solo - Yogyakarta - NYIA Kulon Progo toll road project is located in Central Java which passes through local settlements, access by heavy equipment vehicles will be limited. This study aims to determine the specifications and productivity of heavy equipment at STA 14+000 - 15+000 using a quantitative descriptive method. The heavy equipment studied is an excavator, dump truck, bulldozer, vibratory roller, sheep foot roller, and motor grader. After the calculation, the production results of the equipment per hour are as follows: dump truck 3,56 m3/hour; excavator 65,94 m3/hour; bulldozer 468 m3/hour; vibratory roller 105,67 m3/hour; sheep foot roller 105.67 m3/hour; motor grader 156.61 m3/hour. The duration of soil excavation work was 58 days, soil backfill work was 60 days, and geotextile and LPA backfill work was 60 days with the total duration required for earthworks of 178 days or 5.9 months 2 days faster than the planned time.

Kata Kunci :
Durasi; Produktivitas; Alat berat

Abstrak
Proyek jalan tol Solo - Yogyakarta - NYIA Kulon Progo terletak di Jawa Tengah yang melewati pemukiman penduduk setempat, sehingga akses kendaraan alat berat akan terbatas. Penelitian ini bertujuan untuk mengetahui spesifikasi dan produktivitas alat berat pada STA 14+000 - 15+000 dengan menggunakan metode deskriptif kuantitatif. Alat berat yang diteliti adalah excavator, dump truck, bulldozer, vibratory roller, sheep foot roller, dan motor grader. Setelah dilakukan perhitungan, hasil produksi alat per jam adalah sebagai berikut: dump truck 3,56 m3/jam; excavator 65,94 m3/jam; bdozer 468 m3/jam; vibratory roller 105,67 m3/jam; sheep foot roller 105,67 m3/jam; motor grader 156,61 m3/jam. Durasi pekerjaan galian tanah adalah 58 hari, pekerjaan timbunan tanah 60 hari, dan pekerjaan geotextile dan timbunan LPA 60 hari dengan total durasi yang dibutuhkan untuk pekerjaan tanah adalah 178 hari atau 5,9 bulan 2 hari lebih cepat dari waktu yang direncanakan.

Article History :
Submitted : 11 Mei 2024
Accepted : 12 Juni 2024
Available Online : Juni 2024

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Sitasi : *Kurniawati, Shevi Adelia Ayu and Putra, I.N.D.P. 2024. Analysis of Heavy Equipment Productivity in the Solo – Yogyakarta – NYIA Kulon Progo Toll Road Construction Project Section 1 Package 1.1. Vol. 03 No. 01. Hal. 1-12.*

1. Introduction

In the era of President Joko Widodo's reign, the government is aggressively encouraging infrastructure growth, one of which is the construction of toll roads. Especially the people of Central Java who are currently in the process of building the Solo - Yogyakarta - NYIA Kulon Progo section 1 package 1.1 toll road. It is hoped that the construction of a toll road connecting Solo Regency to the Special Region of Yogyakarta will be able to help the economy of the people of Central Java and can increase regional income whose area is traversed by the toll road, besides that it can also speed up driving travel time from Solo Regency to the Special Region of Yogyakarta.

Development projects will always require assistance in terms of labor, materials, and tools. Likewise, in this toll road construction project, the construction process in this project requires the assistance of heavy equipment vehicles. The purpose of using heavy equipment is to facilitate work and maximize work time effectively. The choice of heavy equipment is also influenced by capital, project type, project location, and so on. This road construction project passes through local settlements so that the access that will be passed by heavy equipment vehicles will be limited, so it is very important to know the specifications and productivity of the equipment used. In this toll road work, heavy equipment such as excavators, dump trucks, bulldozers, vibratory rollers, sheep foot rollers, and motor graders are needed. The effectiveness of the use of heavy equipment can be seen from the amount of production capacity of the tool. In addition, the effectiveness of the work is also inseparable from the method of work and the factors that affect the work. Thus, planning the use of heavy equipment and work methods must be done carefully so that the work time can be achieved by the planned time.

Based on this background, the researcher conducted research on the productivity of heavy equipment on earthworks in the project area by writing a final project entitled "Analysis of Heavy Equipment Productivity on the Solo - Yogyakarta - NYIA Kulon Progo Toll Road Construction Project Section 1 Package 1.1". It is hoped that the author can contribute to the calculation of heavy equipment productivity effectively and efficiently in this road project.

2. Research Methods

In Law Number 22 of 2009 concerning road traffic and transportation, it is understood that roads are land transportation infrastructure which includes all parts of the road, including complementary buildings and equipment intended for traffic, which are at ground level, above ground level, below ground level, below water level, and above water level, except railways and cable roads. Road parts are parts that include road use space, road property space, and road monitoring space. Roads are divided into several types, namely public roads, freeways, special roads, and toll roads (Minister of Public Works and Public Housing of Indonesia Regulation No. 13/PRT/M/2011, 2011).

A toll road is a freeway that is part of the road network system and is a national road whose users are required to pay (Law Number 2 of 2022, 2022). Meanwhile, the intended freeway is a public road for traffic with full control of the entrance and without any level intersections and is equipped with toll road space fences (Minister of Public Works and Public Housing of Indonesia Regulation No. 5, 2023).

According to Government Regulation of the Republic of Indonesia, Number 15 of 2005 Article 66 No. 1, toll road usage rates are calculated based on the ability to pay road users, the amount of profit from vehicle operating costs, and the feasibility of investment.

Heavy Equipment Management

Heavy equipment selection and control management is the process of planning, leading, and controlling heavy equipment to achieve planned work objectives. To avoid mistakes in the selection of heavy equipment (Kalalo et al., 2020). Several factors must be considered, including the following:

a. Heavy equipment function
   Heavy equipment is grouped based on its function, such as digging, transporting materials, and leveling surfaces.

b. Equipment capacity
   Each machine has a certain volume capacity according to the weight of the material or the total volume to be worked on. The capacity of the selected heavy equipment must be to the needs of the work so that the work can be completed according to the planned time.

c. Mode of operation
The way heavy equipment works varies based on horizontal and vertical direction, and the distance of movement, speed, and frequency of movement.

d. Capital
An important factor to consider when selecting heavy equipment, in addition to investment costs and equipment rental costs, there are also operating costs and equipment maintenance costs.

e. Project type
Not all projects use heavy equipment assistance, generally only large projects use heavy equipment, such as building projects, roads, bridges, ports, forest clearing, irrigation, and dams.

f. Project location
The location of the project is one of the important factors that must also be considered when selecting heavy equipment, such as road construction projects that pass through residential areas, in this case, the selection of heavy equipment must be adjusted to the conditions around the project site that will be passed.

g. Type and bearing capacity of soil
No less important, the type and carrying capacity of the soil must also be considered when selecting heavy equipment to be used, because the soil has several conditions such as solid, loose, or mushy conditions.

h. Field conditions
Conditions with difficult terrain such as uphill or downhill will also affect the selection of heavy equipment.

Soil Properties

Before doing earthwork, it is mandatory to know the properties of the soil to be used. This is because the soil will experience changes in volume and density during the process of transportation, transfer, and re-surfacing (Minister of Public Works and Public Housing of Indonesia Regulation No. 13/PRT/M/2011, 2011). The various soil properties are as follows:

a. Bank measure
The state of the soil before work is carried out or a natural state and has not experienced technological disturbances such as vehicle traffic, excavation, removal, transportation, and compaction.

b. Loose measure
The state of the soil after work such as excavation, transportation, and during the removal process. At this time the soil usually changes in volume due to the addition of air voids in the soil grains.

c. Compact measure
The state of the soil during the backfilling and compaction process. The volume of soil after being compacted may be greater or smaller than the volume at the time of the bank measure. This depends on the compaction effort made.

Heavy Equipment

Heavy equipment is a large machine tool designed to carry out construction functions such as earthworks, road construction, building construction, plantations, and mining. The existence of heavy equipment in every project is very important to support infrastructure development and in exploring mining products. The advantages obtained from using heavy equipment are very fast time, large power, economic value and others (Law Number 2 of 2022, 2022).

Dump Truck

Dump trucks are vehicles specifically made for transportation because of their speed, capacity, and flexibility. Heavy equipment that has a tub at the back that functions to carry materials from one place to another. The materials that can be transported by dump trucks include, for example, dredged soil, sand, split stone, and concrete mixes. The way this truck works is by raising the tub with a hydraulic system to remove the cargo.

Excavator

Excavators are heavy equipment consisting of arms, shoulders, and scrapers shaped like baskets and cabins that are placed on a turret bed that allows them to rotate. Excavators use track shoes as driving wheels. Track shoe is made of iron material which is interconnected between parts.

Bulldozer

Bulldozer is a heavy equipment equipped with a blade or knife located in front of the bulldozer. This heavy equipment functions to spread and flatten large amounts of soil, sand, and gravel material, fill in former excavation holes and pull and push heavy loads to be moved.

Vibratory Roller

A vibratory roller commonly referred to as a vibro roller is heavy equipment used to compact soil. This tool has 2 large tires the front is a drum, and is equipped with a vibrating device as the name implies. The vibration of the vibro roller causes the soil it passes through to fill each other so that the soil becomes denser. There is also a type of vibro roller that has drums at the front and back, the tool is named vibro roller double drum. In general, this machine can compact soil with a thickness of 20 cm to 122 cm.

Sheepfoot Roller

Sheepfoot rollers also known as vibro snails have more or less the same function as vibro rollers. Both function on earthworks, but the difference is that vibro slugs are also used to break large stones. The drum or roller vibro snail surface has large rectangular protrusions that can break rocks.

Motor Grader

Motor graders are heavy equipment that functions to overlay the top foundation layer and finish the embankment. The blade of this machine can be adjusted in such a way that it can be converted into an angled dozer or tilting dozer.

Work Efficiency of Heavy Equipment

The productivity of heavy equipment in reality in the field is not the same when compared to the ideal state of the equipment. This is due to certain factors such as topography, operator ability, operation, and maintenance of the equipment. The productivity per hour of equipment that must be taken into account in planning is the standard productivity of equipment in ideal conditions multiplied by a factor commonly referred to as work efficiency.

The value of work efficiency is difficult to determine precisely, but based on experiences, it can be determined that work efficiency is close to reality(Minister of Public Works and Public Housing of Indonesia Regulation No. 5, 2023).

Table 1. Work Efficiency Factors

Tool operating conditions	Machine maintenance				
	Very Good	Good	Medium	Poor	Very Poor
Very Good	0,83	0,81	0,76	0,70	0,63
Good	0,78	0,75	0,71	0,65	0,60
Medium	0,72	0,69	0,65	0,60	0,54
Poor	0,63	0,61	0,57	0,52	0,45
Very Poor	0,52	0,52	0,47	0,42	0,32

Source: Rochmanhadi (1992)

Productivity Calculation Method of Heavy Equipment

a. Dump Truck

The productivity of a dump truck always depends on the cycle time. The cycle time of a dump truck includes:

- Load time is the time required to load material into the dump truck.
- Departure time is the time required to move the material to the planned location.
- Unloading time is the time required to unload the cargo in the dump truck to the planned place.
- Return time is the time it takes for the dump truck to return to the material pickup location.

Rochmanhadi (1992) states that the formula used to calculate dump truck productivity is as follows:

$$P = \frac{q \; x \; 3600 \; x \; E}{CT} \quad (1)$$

Description:
P = Production per hour (m^3/hour)
q = Production per cycle (m^3)
E = Work efficiency of dump truck
CT = Dump truck cycle time (minutes)

b. Excavator
Calculating excavator productivity is influenced by the type of material. In the excavator productivity calculation formula there is a cycle time and to determine the excavator cycle time is based on the selection of excavator bucket capacity. Excavator cycle time includes:

- Bucket filling time (land bucket)
- The time when swinging with the load (swing loaded)
- Dump bucket time
- Time to swing back when empty (swing empty)

To calculate the productivity of heavy equipment excavator can use the following equation (Rochmanhadi, 1992):

$$Q = \frac{q \; x \; 3600 \; x \; E}{CT} \quad (2)$$

Description:
Q = Production per hour (m3 / hour)
q = Production per cycle (m3)
E = Excavator work efficiency
CT = Excavator cycle time (minutes)

c. Bulldozer
According to Rostiyanti (2008), bulldozer productivity is highly dependent on blade size, tractor capability, and distance traveled. To calculate bulldozer productivity, is determined from the volume of soil moved in one cycle and the number of cycles in one hour of operation. Bulldozer cycle times include:

- Displacing time
- Gear change time
- Reverse time

The formula for calculating bulldozer productivity can use the following equation (Rochmanhadi, 1992) :

$$Q = \frac{q \; x \; 3600 \; x \; E}{CT} \quad (3)$$

Description:
Q = Production per hour (m3 / hour)
q = Production per cycle (m3)
E = Bulldozer work efficiency
CT = Bulldozer cycle time (minutes)

d. Vibratory Roller
The thickness of the backfill layer to be compacted should not be too thick to achieve effective productivity. The recommended compaction thickness ranges from 10 to 20 cm. For pneumatic rollers, the compaction thickness is 30 cm while for vibratory rollers the thickness depends on the type of soil and the weight of the equipment used. For grained soil types, the recommended effective thickness ranges from 20 to 122 cm depending on the weight of the tool and for rocks, the

thickness can reach 2.1m. The formula for calculating vibro roller productivity can use the following equation (Rostiyanti, 2008) :

$$Q=\frac{(N(b-bo)+bo)x\ v\ x\ 1000\ x\ Fa\ x\ t}{N\ x\ n} \quad (4)$$

Description:
Q = Production per hour (m3/hour)
b = Compaction width in one pass (m)
be = Effective width (m)
b0 = Overlap width (m)
W = Width of compaction area (m)
t = Planned thickness (cm)
v = Planned speed (km/jam)
n = Number of compaction passes
N = Number of passing lanes

e. Sheepfoot Roller
Sheepfoot rollers are used on sandy loam soil types with an effective compaction depth of approximately 15 to 25 cm. Each compaction process is carried out in an overlap of approximately 30 cm. The formula for calculating sheepfoot roller productivity is as follows:

$$Q=\frac{(N(b-bo)+bo)x\ v\ x\ 1000\ x\ Fa\ x\ t}{N\ x\ n} \quad (5)$$

Description:
Q = Production per hour (m3/hour)
b = Compaction width in one pass (m)
be = Effective width (m)
b0 = Overlap width (m)
W = Width of compaction area (m)
t = Planned thickness (cm)
v = Planned speed (km/jam)
n = Number of compaction passes
N = Number of passing lanes

f. Motor Grader
Calculating the productivity of motor graders on road projects can be calculated based on the distance traveled by the tool per hour, while on other projects it can be calculated by the area per hour. To calculate the productivity of a motor grader, you can use the equation below (Minister of Public Works and Public Housing of Indonesia, 2013) :

$$P=\frac{\boldsymbol{Lh\ x\ (N(b-bo)+bo)x\ t\ x\ Fa\ x\ 60}}{\boldsymbol{N\ x\ n\ x\ Ts}} \quad (6)$$

Description:
Lh = Length of overlay (m)
bo = Overlap width (m)
Fa = Work efficiency factor
n = Number of passes
N = Number of stripping per pass
v = Average speed
b = Blade width
60 = Multiplication of 1 hour to minute
t = Pavement elevation
Ts = Cycle time

Heavy Equipment Unit Price Calculation

Based on the Minister of Public Works and Public Housing of Indonesia Regulation No. 1, 2022, it states that the unit price of work (HSP) is a cost calculated by analyzing the unit price of a work which consists of direct costs and indirect costs as payments for certain types, not including taxes. value added.

a. Equipment unit price per m^3
   The unit price of the equipment is the costs incurred on equipment cost components such as definite costs, uncertain or operational costs, workshop costs, wage costs, repair costs, and operator costs. The unit price of equipment per m3 can be calculated by multiplying the equipment coefficient by the rental equipment price (Minister of Public Works and Public Housing of Indonesia Regulation, 2008)

b. Unit price of material per m^3
   The unit price of materials is the cost incurred on material components to produce a particular unit of work

c. Basic unit price of labor
   The basic unit price of labor per hour can be calculated by multiplying the labor coefficient by the hourly wage.

Methodology

The research method used in the research is a quantitative descriptive method. The research location is in Klaten Regency on the Solo – Yogyakarta – NYIA Kulon Progo toll road construction project section 1 package 1.1 STA 14+000 to STA 15+000. Heavy equipment productivity research is carried out during normal working hours 08.00 - 17.00 WIB with a break of 1 hour at 12.00 - 13.00 WIB. The objects and subjects of this research are Dump trucks, excavators, Vibratory rollers, Sheepfoot rollers, bulldozers, and Motor Grader heavy equipment. To compile this research, the following steps must be taken :

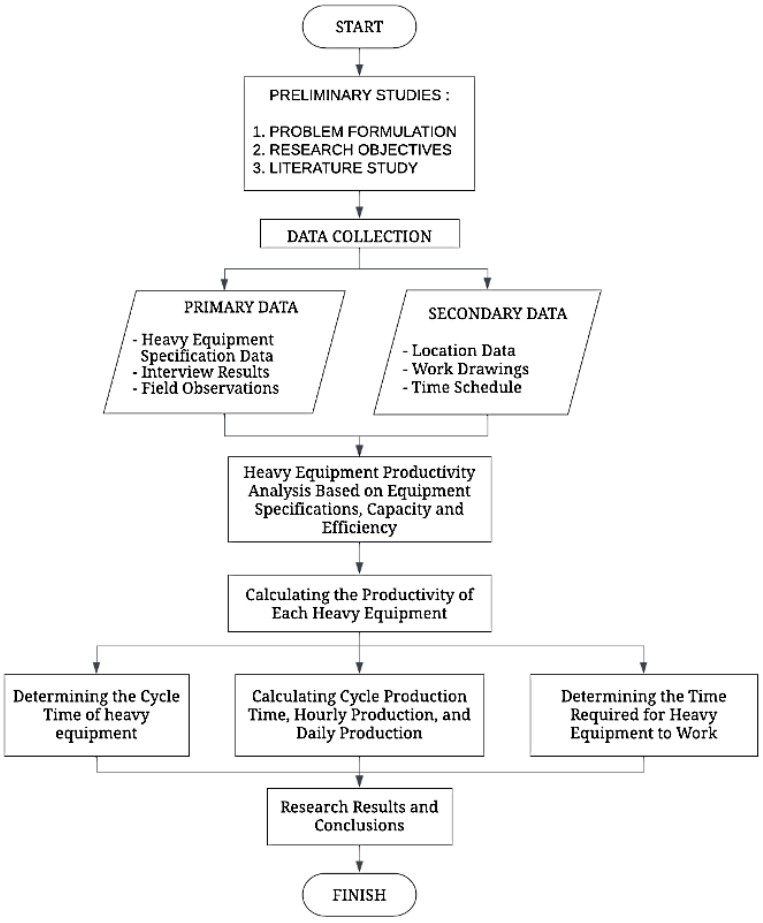

Figure 1. Research Flowchart

3. Results and Discussion

General Data of The Project

Type of Work	: Construction of the Solo – Yogyakarta – NYIA Toll Road Kulon Progo Section 1 Package 1.1
Job Location	: STA 0+000: Junction Kartasura STA 22+300 : Klaten Interchange
Project Owner	: PT. Jogjasolo Marga Makmur
Contractor	: PT. Adhi Karya (Persero) Tbk.
Supervision Consultant	: PT. Eskapindo Matra
Planning Consultant	: PT. Peretjana Djadja
Office Location	: Ngasem, Kec. Colomadu, Karanganyar Regency, Central Java
Implementation Time	: 730 Calendar Days
Research Location	: STA 14+000 – STA 15+000

Result

The types of heavy equipment working on this project include:

1. Isuzu NKR71 HD E2-2 type dump truck
2. Kobelco SK200-10 type excavator
3. Caterpillar CS533E type vibratory roller
4. Caterpillar CS533E type sheepfoot roller
5. Komatsu D85ESS-2 type bulldozer
6. Changlin Grader-713H type motor grader

The total volume of soil in the earthworks is obtained as follows:

Excavated soil volume = 74221,45 m^3
Volume of embankment = 275737,38 m^3
Geotextile volume = 5253 m^3

Based on soil volume, type of heavy equipment and formula numbers 1 to 6, the following results are obtained :

Table **2.** Recapitulation of Heavy Equipment Productivity

Tool	Daily Production	Hourly Production
Dump truck	28,48	3,56
Excavator	527,52	65,94
Bulldozer	3744	468
Vibratory roller	845,36	105,67
Sheepfoot roller	845,36	105,67
Motor grader	1252,88	156,61

Calculation of Time Required on Site

1. Earth Excavation Work
   Earth excavation work uses 1 excavator unit and 45 units dump trucks, so the time required is:

   Excavator type Kobelco SK200-10 1 unit
   1 x 65,94 = 65,94 m^3/hour

   Dump Truck type Isuzu NKR71 HD E2-2 45 units
   45 x 3,56 = 160,2 m^3/hour

   Time required :

   Excavated soil volume = 74221,45 m^3

The formula used to calculate the time required is as follows (Putra, 2022) :

$\frac{74221,45}{160,2}$ = 463,3 hours
$\frac{463,3}{8\ x\ 30}$ = 1,93 months

So with 1 excavator and 45 dump trucks it can be completed in 1,93 months or 58 days, slightly faster than the planned time of 60 days.

2. Soil Compaction Work
Soil compaction work uses 158 dump trucks, 1 bulldozer, 1 vibro roller and 1 sheepfoot roller. So the time required is:

Dump Truck type Isuzu NKR71 HD E2-2 158 units
158 x 3,56 = 562,48 m^3/hour

Bulldozer type Komatsu D85ESS-2 1 unit
1 x 468 = 468 m^3/hour

Vibratory roller type Caterpillar CS533E 1 unit
1 x 105,67 = 105,67 m^3/hour

Sheepfoot roller type Caterpillar CS533E 1 unit
1 x 105,67 = 105,67 m^3/hour

Time required :
Volume of embankment = 275737,38 m3
$\frac{275737,38}{562,48}$ = 490,22 hours

$\frac{490,22}{8\ x\ 30}$ = 2,0 months

So with 1 bulldozer unit, 1 vibratory roller unit, 1 sheepfoot unit and 158 dump truck units, it can be completed within 2 months or 60 days according to the predetermined schedule.

3. Geotextile Work
Geotextile and LPA embankment work using 1 unit of vibratory roller, 1 unit of motor grader, and 3 units of dump trucks. So the time required is:
Dump truck type Isuzu NKR71 HD E2-2 3 units
3 x 3,56 = 10,68 m^3/hour

Vibratory roller type Caterpillar CS533E 1 unit
1 x 105,67 = 105,67 m^3/hour

Motor grader type Caterpillar CS533E 1 unit
1 x 156,61 = 156,61 m^3/hour

Time required :
Volume of LPA embankment soil = 5253 m^3
$\frac{5253}{10,68}$ = 491,85 hours
$\frac{491,85}{8\ x\ 30}$ = 2,0 mo nths

So with 3 units of dump trucks, 1 unit of vibratory roller and 1 unit of motor grader it can be completed in 2 months or 60 days, slightly faster than the planned time of 60 days.

Recapitulation of number of heavy equipment and duration of work

Table 3. Recapitulation of Work Duration

Type of Work	Type of Heavy Equipment	Heavy Equipment Productivity	Volume	Plan Complete	Quantity	Duration Complete
		(m^3/hour)	(m^3)	(day)	(unit)	(day)
Earth Excavation Work	Dump truck	3,56	74221,45	60	45	58
	Excavator	65,94	74221,45		1	
Soil Compaction Work	Dump truck	3,56	275737,38	60	158	60
	Bulldozer	468	275737,38		1	
	Vibratory roller	105,67	275737,38		1	
	Sheepfoot roller	105,67	275737,38		1	
Geotextile and LPA Embankment Work	Dump truck	3,56	5253	60	3	60
	Vibratory roller	105,67	5253		1	
	Motor grader	156,61	5253		1	

Based on the results of the analysis in Table 3, the duration of earth excavation work is 58 days, earth embankment work is 60 days, and geotextile and LPA embankment work is 60 days. If all the durations are added up, the time required will be 5,9 months or 178 days. The heavy equipment used in this work is:

1. Earth Excavation Works
   - Isuzu NKR71 HD E2-2 type dump truck 45 units
   - Kobelco SK200-10 type excavator 1 unit
2. Soil Compaction Work
   - Isuzu NKR71 HD E2-2 type dump truck 158 units
   - Komatsu D85ESS-2 type bulldozer 1 unit
   - Caterpillar CS533E type vibratory roller 1 unit
   - Sheepfoot roller type Caterpillar CS533E 1 unit
3. Geotextile and LPA Embankment Works
   - Isuzu NKR71 HD E2-2 type dump truck 3 units
   - Caterpillar CS533E type vibratory roller 1 unit
   - Caterpillar CS533E motor grader 1 unit

4. Conclusion

Based on the results of heavy equipment productivity research that has been carried out, the following conclusions are obtained:

For earthworks at STA 14+000 to STA 15+000, the results obtained from the combination of heavy equipment used are : 45 units of Isuzu NKR71 HD E2-2 type dump truck and 1 unit of Kobelco SK200-10 type excavator for earth excavation work. 158 units of Isuzu NKR71 HD E2-2 type dump truck; 1 unit of Komatsu D85ESS-2 type bulldozer; 1 unit of Caterpillar CS533E type vibratory roller; and 1 unit of Caterpillar CS533E type sheepfoot roller for earth filling work. 3 units of Isuzu NKR71 HD E2-2 type dump truck; 1 unit of Caterpillar CS533E type vibratory roller; and 1 unit of Caterpillar CS533E type motor grader for geotextile work and LPA embankments.

The productivity of each heavy equipment used is as follows: production of dump truck = 3,56 m3/hour, production of excavator = 65,94 m3/hour, production of bulldozer = 468 m3/hour, production of vibratory roller = 105,67 m3/hour, production of sheepfoot roller = 105,67 m3/hour, production of motor grader = 156,61 m3/hour.

A total volume of earthwork is 355.211.83 m3, it can be completed with the duration required for each work item being as follows: The volume of earth excavation work of 74221,45 m3 could be completed within 58 days, the volume of earth embankment work of 275737,38 m3 could be completed within 60 days, the volume of geotextile work and LPA embankment of 5253 m3 can be completed within 60 days.

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