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Expansion joint technology in bridge: A review

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Abstract
Bridge is important mean in land transportation. Therefore, all the supporting details of the bridge need to be considered. One of the parts for the bridge is the expansion joint. Expansion Joint is a material that is installed between two areas of concrete floors joints to accommodate expansion of the bridge structures and materials deformation due to temperature changes, and physical properties (creep and shrinkage) of the bridge. There are various types and materials of expansion joint. A case study of expansion joint analysis is discussed. It is concluded that expansion joint type in bridge should consider the use of local raw materials, the easiness of maintenance, the comfort and safety for road users, costs, schedule, and the installation works.

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Introduction

Damage in bridges causes not only traffic stagnation and economic losses but also loss of human lives. Therefore, damage identification and condition assessment of bridges are a main task of infrastructure management communities to ensure safety in operation (Nguyen, 2021) [6]. Progress and economic growth will increase human activity itself so that transportation facilities and infrastructure are needed. In connection with the functions and needs of the road as a means of transportation, it is necessary to pay attention to the details of road support. One of the parts for the bridge is the expansion joint. Expansion Joint is a material that is installed between two areas of concrete floors joints to accommodate expansion of the bridge structures and materials due to creep, shrinkage, and temperature changes.

There are two types of expansion joint, namely open joint and closed joint. Each type of expansion joint certainly offers its own advantages and disadvantages, both in terms of its performance to accommodate deformation of bridge, and the cost and schedule of construction and maintenance of the bridge (Florida Department of Transportation, 2023) [4].

The objective of this paper is to study the types of expansion joints. Furthermore, this study aims to analyze the unit price, time schedule, and installation of expansion joints.

Methodology

The methodology includes literature study and field survey of the case study location. The literature study is on the types and unit price of expansion joints. The field survey was conducted to determine the expansion joint minimum gap requirement condition of the existing Suren Bridge (Jember Regency-East Java Province, Indonesia). The method of data collection is conducted by field observation using the national bridge survey guideline. Based on the minimum gap requirement, the type of expansion joint is determined. Then the unit price, time schedule, and installation work of selected expansion joint is discussed.

Literature Review

Expansion joint

Expansion Joint is a type of connection used to connect concrete in a bridge construction to accommodate expansion of the bridge structures and materials due to temperature changes. With this connection, vehicles can pass safely over the bridge.

Expansion joints are commonly installed on two planes of concrete floor or rigid pavement. Expansion joints are most commonly used in bridge construction. This section can be seen easily with the naked eye. Expansion Joints must continuously prevent water intrusion through the permeable road surface and withstand the hydraulic pressure of water created by traffic movement (Sebayang and Wajhahu, 2023) [8].

Function of the Expansion Joint is to accommodate the movement that occurs in the superstructure of the bridge. This movement originates from live loads, temperature changes, and the physical properties of the bridge. Although it seems simple, the expansion joint on the bridge actually has such a large function. The expansion joint is also an attempt to maintain the shape of the bridge structure. As a result of several factors previously mentioned, the bridge may change shape (Transportation Research Board, 2003) [7].

With the presence of expansion joints, the bridge becomes more ready to accept loads and accommodate the movements that arise. This movement can be caused by live loads, the physical properties of the bridge structure, and temperature changes that cause expansion and contraction. In addition, the function of the expansion joint is to dampen vibrations that may arise due to loads on the surface of the bridge. The expansion joint is also an effort to maintain the shape of the bridge structure (Transportation Research Board, 2003) [7].

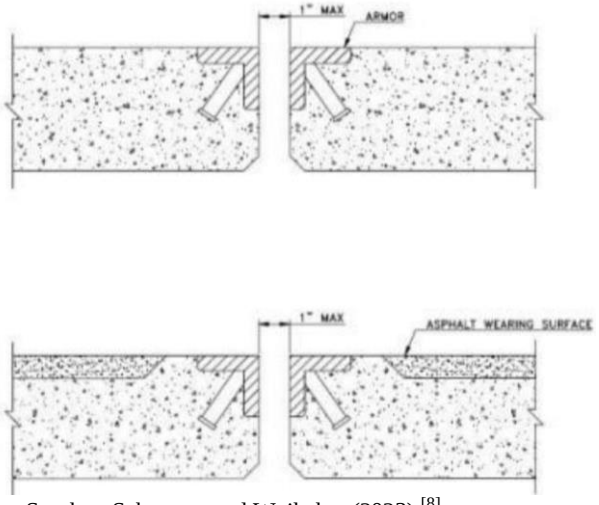
Types of Expansion Joint

According to the Florida Department of Transportation (2023) [4] and Sebayang and Wajhahu (2023) [8], expansion joints are divided into 2 types: open joints and closed joints. Closed joints are designed to be watertight, while open joints are not.

- **Open Expansion Joint.** In open expansion joints, a drainage system is placed under the joint to collect and carry water to the disposal. The types of open expansion joints are butt joints and finger joints.

a. Butt Joint

Butt joint is a joint that uses angled steel to protect the edges of the concrete from damage caused by passing vehicles. This joint is used for bridges with small movements, with a maximum gap of 25 mm (Figure 1).

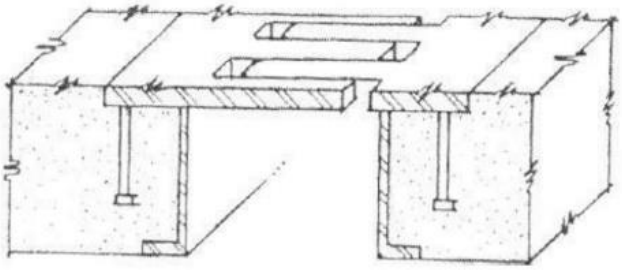


Sumber: Sebayang and Wajhahu, (2023) [8]

Fig 1: Butt Joint

b. Finger Joint

The finger joint can accommodate movements starting from 75 mm. The finger joint is made of steel and is shaped like two combs that tie together. Because the finger joint is included in the open type of joint, it is given drainage under the joint (Figure 2).



Sumber: Sebayang and Wajhahu, (2023) [8]

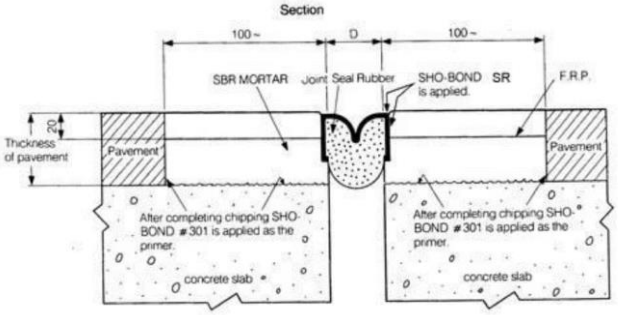
Fig 2: Finger Joint

- **Closed Expansion Joint**

The types of closed expansion joints are New Cut Off Joints, Asphaltic Plug Joints, Strip Seal Joints, and Modular Joints.

a. New Cut Off Joint (NCOJ)

The New Cut Off Joint is an expansion joint that uses a rubber-based seal. Seals are placed between the gaps to withstand the movement that occurs on the bridge. This joint is used for bridges with small movements, with a maximum gap of 20 mm (Figure 3).

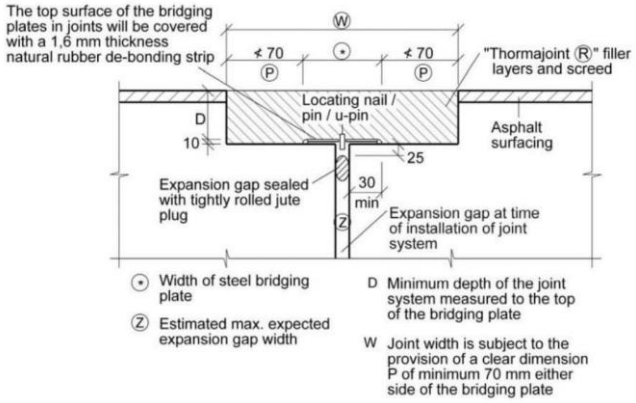


Sumber: Sebayang and Wajhahu, (2023) [8]

Fig 3: New Cut off Joint

b. Asphaltic Plug Joint

Asphaltic Plug Joint is an expansion joint made of aggregate material mixed with binder, steel plate and anchor, made at a certain temperature which functions as a filler material in the joint. This joint is used for bridges with small movements, with a maximum gap of 20 mm (Figure 4).

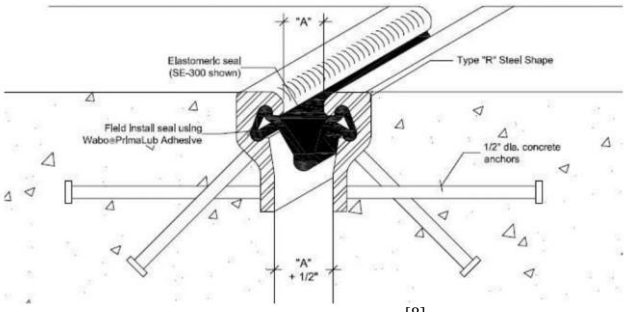


Sumber: Sebayang and Wajhahu, (2023) [8]

Fig 4: Asphlatic Plug Joint

c. Strip Seal Joint

Strip Seal Joint is in the form of a strip made of elastomer which is inserted into an iron that is embedded in a concrete slab. Strip Seal Joint has several types for various movements. The largest Strip Seal Joint sizes can handle movements up to 125mm, but for safety most people limit it to 100 mm (Figure 5).

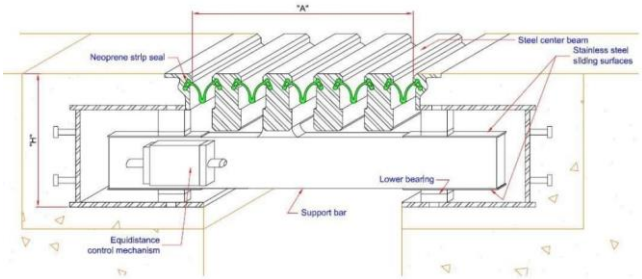


***Source*:** Sebayang and Wajhahu, (ny2023) [8]

Fig 5: Strip Seal Joint

d. Modular Joint

Modular Joints are made to accommodate movements of more than 100 mm. The size of the modular joint depends on the size of the movement. Modular joints are designed for bridges with long spans with a movement capability of up to 2 m. Usually modular joints are used for movements between 150 mm and 600 mm (Figure 6).



***Source*:** Sebayang and Wajhahu, (2023) [8]

Fig 6: Modular Joint

Unit price of expansion joint

In this section, all prices are based on the Journal of Building Materials and Interior for Jakarta Province 2023 (Jakarta Province, 2023).

1. Butt Joint

Assuming that the butt joint uses angle steel 70 mm x 70 mm x 7 mm, and with anchors using steel with a diameter of 16 mm and a length of 15 cm with a distance between anchors of 20 cm. obtained a total weight of 9.67 kg. And the market price of steel is IDR 9,500/kg. So the price for the butt joint material is IDR 91,865/m'.

2. Finger Joint

Assuming the finger joint uses a steel plate with a thickness of 16 mm, a width of 300 mm, a length of 1 m, and uses a steel anchor with a diameter of 16 mm and a length of 150 mm with a total of 28 anchors. Then the total weight is 50.93 kg. The market price of steel is IDR 9,500/kg. Then the total price of the finger joint material is IDR 483,835/m'.

3. New Cut Off Joint

The finished price of the new cut off joint with a 20 mm Gap is IDR 2,900,000/m2. With a gap of 30 mm IDR 3,450,000/m'. And with a gap of 40 mm IDR 3,850,000/m'.

4. Strip Seal Joint

The finished price of the strip seal joint for the Wabo brand with SMM specifications of 100 IDR 5,750,000/m'. Specifications for SMM 125 IDR 6,150,000/m'. With SMM 100 IDR 5,000,000/m'.

5. Modular Joint

The price for a modular joint according to the Wabo brand with a specification of SDM 160 (total movement 160 mm) IDR 39,000,000/m'. The SDM 200 specifications (total movement 200 mm) IDR 42,750,000/m'. SB 240 specifications (total movement 240 mm) Rp. 52,500,000/m'. SB 320 specifications (total movement 320 mm) IDR 75,000,000/m'. SB 400 specifications (total movement 400 mm) IDR 115,900,000/m'. SB 480 specifications (total movement 480 mm) IDR 145,350,000/m'.

6. Asphaltic Plug Joint

The finished price of the asphaltic plug joint with a Gap of 20 mm is IDR 1,350,000/m'. With a gap of 30 mm IDR 1,500,000/m'.

It can be seen that the gap capacity and the price of each expansion joint types varies so that to choose the best type of expansion joint in a bridge work has to be in line with the minimum gap of each bridge work and the work cost budget.

A case study of expansion joint analysis

A case study was carried out at the Suren Bridge (with 8.8 m span) in Jember Regency-East Java Province, Indonesia, that discusses the selection of the type of expansion joint that will be used.

Minimum Gap Requirement Identification

The time of the field survey was carried out for 4 days by observing bridge movements and identifying bridges using the Indonesian national guideline Regulation no. 04/P/BNKT/1991 and BMS2-M.1 of 1993 concerning Guidelines for Bridge Inspection.

From the field survey data and calculations based on the guideline, it is discovered that:

1. The girder bridge has a length of 8.8 m, made of concrete quality of 29 MPa, and the temperatures in the field are maximum of 40ºC and minimum of 27ºC.
2. Deformation due to concrete creep is $\Delta cr = 3.009$ mm
3. Deformation due to concrete shrinkage is $\Delta sh = 0.873$ mm
4. Deformation due to changes in temperature is $\Delta Ltemp = 0.572$ mm
5. Based on Indonesian national guideline formula (Badan Standardisasi Nasional, 2007) the expansion joint gap is:

Δexpansion joint = $\Delta cr+\Delta sh + 2\Delta temp$
Δexpansion joint = 3.009 + 0.873 + (2 * 0.572)
Δexpansion joint = 5.026 mm

Selection of Expansion Joints

For a minimum gap width of 5,026 mm, the type of joint that can be an efficient choice based on types of expansion joint

review above in section 4 is:

1. Using Butt Joints (max gap = 25 mm)
2. Using New Cut Off Joints (max gap 20 mm)
3. Using Asphaltic Plug Joints (max gap 20 mm)
4. Using Butt Joint with rubber seal (max gap 25 mm)

In this case study, the Asphaltic Plug Joint is selected, because

- Locally produced raw materials that are easy to obtain so thus low implementation costs with a relatively short implementation time and is able to meet good performance to accommodate an expansion gap movement of 20 mm.
- easy maintenance, and good comfort for bridge users

Cost Estimate

Cost estimate is the amount of costs needed both wages and materials in a construction project. Cost estimating before carrying out construction work can reduce cost overruns risks and optimum manpower, so that we can get maximum results at more efficient cost.

Unit Price Analysis

The following is an example of calculating the analysis of the 1 meter of expansion joint work unit price. The coefficients of manpower and materials are in accordance with the unit price analysis national guideline in Indonesia. All prices are based on the Journal of Building Materials and Interior for Jakarta Province 2023 (Table 1).

Table 1: Unit Price Analysis

NO	Job Deskription	Unit	Coefficient	Unit Price (IDR)	Total (IDR)
a	b	c	d	e	f=d*e
1	**Early Work**				
a	▪ Land Preparation				
	▪ Foreman	Man-day	0.022	90,000	1,980
	▪ Worker	Man-day	0.22	60,000	13,200
		Total Labor Prices			**15,180**
2	**Structure Work Dismantling of Existing Connections**				
a	▪ Foreman	Man-day	0.064	90,000	5,760
	▪ Craftsman	Man-day	0.227	70,000	15,890
	▪ Worker	Man-day	0.5	60,000	30,000
		Total Labor Prices			**51,650**
b	**Installation of the Connection Gap Plate**				
	▪ Foreman	Man-day	0.064	90,000	5,760
	▪ Craftsman	Man-day	0.227	70,000	15,890
	▪ Worker	Man-day	0.5	60,000	30,000
		Total Labor Prices			**51,650**
	Material				
	▪ Iron Plat 6 mm	Sheet	0.071	1,648,000	117,714
	▪ Asphaltic Plug	Pack	0.08	425000	34,000
		Total price of materials			**151,714**
		Total labor prices			**203,364**
c	**Mixing Aggregate with Asphaltic**				
	▪ Foreman	Man-day	0.064	90,000	5,760
	▪ Craftsman	Man-day	0.227	70,000	15,890
	▪ Worker	Man-day	0.5	60,000	30,000
		Total Labor Prices			**45,890**
	Material				
	▪ Aspaltic Plug	Pack	0.32	425000	136,000
	▪ Split	Cubic-M	0.0014	380,000	5,320
		Total price of materials			**141,320**
		Total labor prices			**187,210**
d	**Compaction**				
	▪ Foreman	Man-day	0.064	90,000	5,760
	▪ Craftsman	Man-day	0.227	70,000	15,890
	▪ Worker	Man-day	0.227	60,000	13,620
		Total Labor Prices			**35,270**
3	**Finishing**				
a	**Liquid binder pouring**				
	▪ Mandor	Man-day	0.064	90,000	5,760
	▪ Pekerja	Man-day	0.5	60,000	30,000
		Total Labor Prices			**35,760**
	Material				
	▪ Aspaltic Plug	Pack	0.02	425,000	8,500
	▪ Paper tape	Roll	0.2	9,000	1,800
		Total price of materials			**10,300**
		Total labor prices			**46,060**
	Total Unit Cost of Expansion Join for 1 meter				**534,974**

Asphalt Plug Expansion Joint Installation Method
The following are the stages of the implementation method taken from Indonesian national guideline (Citra marga, 2007; Departemen Pekerjaan Umum, 2005).

1. Marking Out
The width of the joint is marked according to the width and size. It is conducted by drawing a straight line from end to end.

2. Cutting and Dismantling Connections
The surface asphalt is cut in the area where the bridge connection will be installed until the surface of the concrete floor is made perpendicular according to the marking line, then it is dismantled using a jack hammer with a high pressure compressor power; the visible part must be cleaned from the remnants of asphalt with a wire brush.

3. Marking Out
The width of the joint is marked according to the width and size. It is conducted by drawing a straight line from end to end.

4. Mine Installation
Before pouring the binder on a visible surface, a mine is installed in the concrete gap to clog it so that the binder does not penetrate to the bottom of the bridge.

5. Coating with Binder
The visible surface is coated with binder.

6. Installation of Iron Plates
When installing the iron plate, the surface of the iron plate must be coated again with binder until it is evenly distributed, the temperature of the binder must always be controlled not to be below 190° C.

7. Aggregate heating
Aggregate preparation by heating to a minimum temperature of 150° C using a Hot Compress Air Lance, but not more than 190° C.

8. Binder Pouring
After the aggregate is laid out, the binder is immediately poured until all the aggregate is submerged to a depth of 50 mm. To ensure that all the aggregate is covered by the binder, the aggregate must be leveled with a pitchfork or shovel, the temperature must always be at 190° C - 220° C.

9. Entire Cavity Penetration in Aggregate Gap
Let it be for a while so that the binder can flow and fill all the voids in the aggregate gaps; it is indicated by the presence of air bubbles on the surface of the binder.

Aggregate Mixing
After ensuring that air bubbles do not occur again, a second layer is carried out by pouring the aggregate which has been coated with a binder with a depth of 25 mm. The coating of the aggregate is processed by inserting the aggregate into the Mixer while heating it with a Hot Compress Air Lance at the same time the binder is poured.

10. Compaction
The second layer must be compacted until it is flush with the road surface.

11. Finishing
Cover layer with binder on the surface that has been compacted, this layer is a thin layer as a waterproof material.

Schedule and Working Time
The volume of work is discovered 17.6 meter. The jobs and the man power to install the asphalt plug expansion joint are shown in Table 2. The productivity is calculated by deviding total man power with the coefficient. The coefficients of manpower are in accordance with the unit price analysis national guideline in Indonesia (Table 2). For example, for land preparation, the foreman productivity is 1 devided by 0.022 = 45.45 meter per day. For 17.6 meter work the duration is 17.6 devided by 45.45 = 0.4 day. The total work time is the maximum duration of all. After we know the total work time of each job description, a time schedule using the Bar Chart method is made (Tabel 3). It is assumed that each job can be overlapped around 50%-60%. It can be seen the total work of 17,6 meter the asphalt plug expansion joint is 15 Days.

Table 2. Work productivity schedule for Suren Bridge Expansion Connections

NO	Job Description	Unit	Coefficient	Total Man Power	Productivity	Job Volume (meter)	Duration (Days)	Rounding
a	**b**	**c**	**d**		**e**	**f**	**g**	**h=d*e**
1	**Early Work**					**17.6**		
a	Land Preparation							
	- Foreman	Man-day	0.022	1	45.45		0.4	
	- Worker	Man-day	0.22	1	4.55		3.9	
				Total Work Time (take the maximum_			**3,9**	**4 Days**
2	**Structure Work**					**17.6**		
a	Dismantling of Existing Connections							
	- Foreman	Man-day	0.064	1	15.63		1.1	
	- Craftsman	Man-day	0.227	1	4.41		4.0	
	- Worker	Man-day	0.5	2	4.00		4.4	
				Total Work Time			**4.4**	**5 Days**
b	Installation of the Connection Gap Plate					**17.6**		
	- Foreman	Man-day	0.064	1	15.63		1.1	
	- Craftsman	Man-day	0.227	1	4.41		4.0	
	- Worker	Man-day	0.5	2	4.00		4.4	
				Total Work Time			**4.4**	**5 Days**

c	Mixing Aggregate with Asphaltic					**17.6**		
	- Foreman	Man-day	0.064	1	15.63		1.1	
	- Craftsman	Man-day	0.227	1	4.41		4.0	
	- Pekerja	Man-day	0.5	2	4.00		4.4	
				Total Work Time			**4.4**	**5 Days**
d	Compaction					**17.6**		
	- Foreman	Man-day	0.064	1	15.63		1.1	
	- Craftsman	Man-day	0.227	1	4.41		4.0	
	- Worker	Man-day	0.227	2	8.81		2.0	
				Total Work Time			**4.0**	**4 Days**
3	**Finishing**					**17.6**		
a	Liquid binder pouring							
	- Foreman	Man-day	0.064	1	15.63		1.1	
	- Worker	Man-day	0.5	2	4.00		4.4	
				Total Work Time			**4.4**	**5 Days**

Table 3: Bar Chart of the Suren Bridge work

No	Job Description	Volume	Unit	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15
I	EARLY WORK																	
1	Land Preparation	1	LS															
II	SRUCTURE WORK																	
1	Dismantle of Existing	17,6	M															
2	Installation of the Gap Plate	17,6	M															
3	Mixing Aggregate with Asphalt	17,6	M															
4	Compaction	17,6	M															
III	FINISHING																	
1	Liquid binder pouring	17,6	M															

7. Conclusion

The types of expansion joints are very diverse and will continue to grow along with the times and technology advancement. Each type of expansion joint has different expansion capacity and unit price. Furthermore, it can be concluded that expansion joint type in bridge should consider the use of local raw materials, the easiness of maintenance, the comfort and safety for road users, cost estimate, time schedule, and the installation works.

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