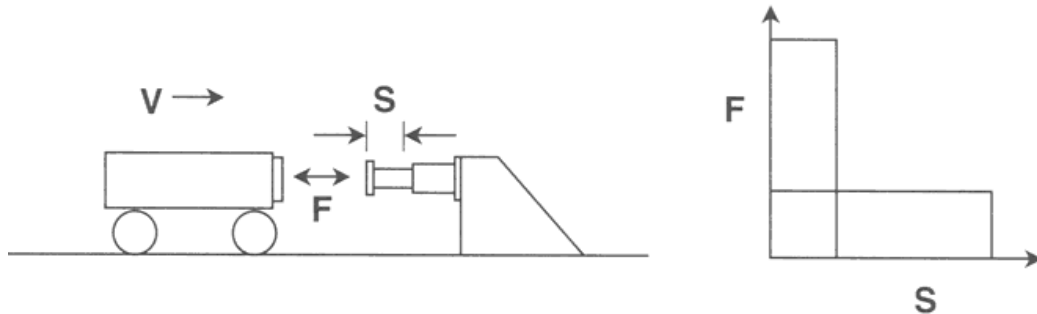


BODIES IN MOTION

Kinetic Energy is associated with a body in motion. Newton's 1st Law of Motion states that a body will continue in motion unless acted upon by a force. An Oleo Hydraulic Bumper will control the magnitude and duration of this force. Newton's 2nd Law of Motion provides that the rate of change of motion is proportional to the force applied. An Oleo Hydraulic Bumper ensures that the force applied is always the minimum required to produce the desired change in motion. Newton's 3rd Law of Motion identifies that for every action there is an equal and opposite reaction. An Oleo Hydraulic Bumper controls the arresting force and limits the reaction on the supporting structure. These principles are the foundation for understanding the benefits and characteristics of a hydraulic energy absorber such as the Oleo Hydraulic Bumper.

KINETIC ENERGY

A body in motion, such as a crane, has kinetic energy that must be dissipated to bring it to rest. A hydraulic bumper produces a resistive force over a displacement to dissipate the energy by converting work energy to thermal energy. The bumper forces oil through a variable orifice to produce fluidic friction and therefore a resisting force.



The graph above on the right shows equal amounts of kinetic energy (represented by the area under the Force vs. Stroke curve) being absorbed with different stroke lengths. As you can see, the more stroke, the lower the resistive force. This resistive force is proportional to the rate of change of motion, or deceleration. Ultimately, the Oleo bumper governs the magnitude of force transmitted to both the impacting body as well as the reaction force onto the support or fixed structure.

PROPELLING FORCES

In many applications, the body in motion is also being propelled. This propelling force is additive with the Kinetic Energy as it acts through the displacement of the bumper. It is always important to determine whether or not the impacting body will be propelled during the impact and to allow sufficient additional energy capacity. Not all design codes or references include propelling forces, so it is the designer's responsibility to determine when they should be considered.

BUMPER END FORCES AND THE DESIGNER

Oleo bumper end forces can be easily calculated and have been verified through extensive testing. For most applications, a standard hydraulic bumper can be utilized to meet the requirements of typical safety codes. Often, the designer can select a longer stroke bumper to further reduce the transmitted force generating a savings in the cost of structure and sometimes in the machine itself. For applications with impacting speeds above 500 ft/min (2.5 m/sec) or special deceleration requirements, please consult Gantrex for assistance.

DESIGN ASSISTANCE

Gantrex Application Engineers are able to assist you by providing calculations, specifications, computer simulations, CAD drawings or any other technical support you may require.

DEFINITION OF VARIABLES

- | | |
|--|---|
| <p> W_B = Weight of Bridge (lbs)
 W_T = Weight of Trolley (lbs)
 W_{EB} = Effective Weight per Bumper on Bridge (lbs)
 W_{ET} = Effective Weight per Bumper on Trolley (lbs)
 V_B = Maximum Travel Speed of Bridge (ft/sec)
 V_T = Maximum Travel Speed of Trolley (ft/sec)
 $V_{B50\%}$ = 50% of V_B (ft/sec)
 $V_{T50\%}$ = 50% of V_T (ft/sec)
 V_{EB} = Effective Speed Per Case 2-4 Table 1 (ft/sec)
 KE_B = Kinetic Energy per Bumper on Bridge (ft-lbs)
 KE_T = Kinetic Energy per Bumper on Trolley (ft-lbs) </p> | <p> S_{RB} = Minimum Stroke Required for Bridge (in)
 S_{AT} = Minimum Stroke Required for Trolley (in)
 S_{AB} = Stroke Available for Selected Bridge Bumper (in)
 S_{AT} = Stroke Available for Selected Trolley Bumper (in)
 $A_{50\%}$ = Maximum Deceleration at 50% Speed (ft/sec²)
 EF_B = Maximum Bumper End Force Bridge (lbs)
 EF_T = Maximum Bumper End Force Trolley (lbs)
 μ = Oleo Bumper Efficiency varies from .85 to .95 by application. Conservatively use .85 for crane applications. </p> |
|--|---|

TABLE 1
Application for Bumpers of the Same Type Used Together

CASE NO.	1	2	3	4
Impact Condition				
Bumper Arrangement				
Velocity 'V _e '	V	$\frac{V}{2}$	$V_1 + V_2$	$\frac{V_1 + V_2}{2}$
Weight per bumper 'W _e '	W	2W	$\frac{W_1 W_2}{W_1 + W_2}$	$\frac{2W_1 W_2}{W_1 + W_2}$
<p>W = Maximum weight on rail EXCLUDING any SUSPENDED load. V = Maximum velocity.</p>			<p>W_e = Equivalent Weight for Bumper sizing. V_e = Equivalent Velocity for Bumper sizing.</p>	

A. WORKED CRANE EXAMPLE (CASE 1, AIST TR #6)

- Bridge Weight (W_B): 300,000 lbs
 Trolley Weight (W_T): 100,000 lbs
 Bridge Speed (V_B): 6.0 ft/sec
 Trolley Speed (V_T): 3.33 ft/sec

BRIDGE

- Maximum Impact Weight per side (W_{EB}):
 $W_{EB} = \frac{1}{2} (W_B) + .9 (W_T)$
 $W_{EB} = \frac{1}{2} (300,000 \text{ lbs}) + .9 (100,000 \text{ lbs})$
 $W_{EB} = 240,000 \text{ lbs}$
- Kinetic Energy per side (KE_B):
 $KE_B = \left(\frac{1}{2} \right) \left(\frac{W_{EB}}{32.2} \right) (V_B)^2$
 $KE_B = \left(\frac{1}{2} \right) \left(\frac{240,000 \text{ lbs}}{32.2} \right) (6.0 \text{ ft/sec})^2$
 $KE_B = 134,161 \text{ ft-lbs}$
 So Oleo Type 9 has sufficient energy capacity.
- Minimum Stroke Required to meet the suggestions of AIST TR #6 (S_{RB}):
 (For AIST TR #6, $A_{50\%} \leq 16 \text{ ft/sec}^2$ @ 50% speed)

$$S_{RB} = \left[\frac{(V_{50\%})^2 (12 \text{ in})}{(2)(\mu)(A_{50\%})} \right] = \left[\frac{(3.0 \text{ ft/sec})^2 (12 \text{ in})}{(2)(.85)(16 \text{ ft/sec}^2)} \right]$$

$S_{RB} = 4.0 \text{ inches}$

Oleo bumper Type 9 has $S_{AB} = 15.75 \text{ inches}$ so it is acceptable.

- Select Metering Pin from "Type 9" Oleo bumper data sheet, "Metering Pin Selection Table". Maximum impact weight per side (from 1, above):

$W_{EB} = 240,000 \text{ lbs}$

Therefore select metering pin #10 which is good for impact weights up to 330,000 lbs.

- Select options from bumper data sheets including mounting style, protective bellows, marine plating, safety cable, bumper head diameter, foot mounting brackets, high temperature seals, low inflation pressure, etc.
- Specify Oleo Bumper Model: **9SBZ140-10**
 (For rear flange mount, safety cable, #10 metering pin plus any additional options from data sheet.)
- Maximum Bumper End Force (EF_B) to be provided to the building or runway designer.

Oleo bumper Type 9 has $S_{AB} = 15.75 \text{ inches}$ and the sample crane has $KE_B = 134,161 \text{ ft-lbs}$:

$$EF_B = \left[\frac{(KE_B)}{(\mu) \left(\frac{S_{AB}}{12} \right)} \right] = \left[\frac{(134,161 \text{ ft-lbs})}{(.85) \left(\frac{15.75 \text{ in}}{12} \right)} \right]$$

$EF_B = 120,256 \text{ lbs}$

8. Maximum Deceleration at 50% Speed ($A_{50\%}$):

$$A_{50\%} = \left[\frac{(V_{50\%})^2}{(2)(\mu) \left(\frac{S_{AB}}{12} \right)} \right] = \left[\frac{(3.0 \text{ ft/sec})^2}{(2)(.85) \left(\frac{15.75 \text{ in}}{12} \right)} \right]$$

$$A_{50\%} = 4.0 \text{ ft/sec}^2$$

TROLLEY:

1. Maximum Impact Weight per side (W_{ET}):

$$W_{ET} = \frac{1}{2} (WT)$$

$$W_{ET} = \frac{1}{2} (100,000 \text{ lbs})$$

$$W_{ET} = 50,000 \text{ lbs}$$

2. Kinetic Energy per side (KE_T):

$$KE_T = \left(\frac{1}{2} \right) \left(\frac{W_{ET}}{32.2} \right) (V_T)^2$$

$$KE_T = \left(\frac{1}{2} \right) \left(\frac{50,000 \text{ lbs}}{32.2} \right) (3.33 \text{ ft/sec})^2$$

$$KE_T = 8,609 \text{ ft-lbs}$$

Proceed as for bridge bumpers and select:
Oleo Bumper Model 21SBS100-105.

B. WORKED CRANE EXAMPLE (CASE 3. AIST #6)

Crane 1	Crane 2
$W_{B1} = 300,000 \text{ lbs}$	$W_{B2} = 350,000 \text{ lbs}$
$W_{T1} = 100,000 \text{ lbs}$	$W_{T2} = 120,000 \text{ lbs}$
$V_{B1} = 6.0 \text{ ft/sec}$	$V_{B2} = 5.0 \text{ ft/sec}$

1. Maximum Impact Weight per side (W_{EB}) for each crane as per the previous example:

$$W_{EB1} = 240,000 \text{ lbs} \quad W_{EB2} = 283,000 \text{ lbs}$$

Calculate the net effective weight per Table 1:

$$W_{EB} = \left[\frac{(W_{EB1})(W_{EB2})}{(W_{EB1} + W_{EB2})} \right] = \left[\frac{(240,000 \text{ lbs})(283,000 \text{ lbs})}{(240,000 \text{ lbs} + 283,000 \text{ lbs})} \right]$$

$$W_{EB} = 129,866 \text{ lbs}$$

2. Determine the net impact velocity (V_{EB}) per Table 1. Note that AIST TR #6 calls for 70% of the speed of both cranes or 100% of either. Here we use the 70% rule which is greatest:

$$V_{EB} = (.70)(V_{B1}) + (.70)(V_{B2}) = (.70)(6.0) + (.70)(5.0)$$

$$V_{EB} = 7.7 \text{ ft/sec}$$

Kinetic Energy Per Side (KE_B) using W_{EB} and V_{EB} from 1. and 2. above:

$$KE_B = \left(\frac{1}{2} \right) \left(\frac{129,866 \text{ lbs}}{32.2} \right) (7.7 \text{ ft/sec})^2 = 119,561 \text{ ft-lbs}$$

So Oleo Type 9 has sufficient energy capacity.

4. Select Metering Pin from "Type 9" Oleo Bumper data sheet, "Metering Pin Selection Table" using $W_{EB} = 129,866 \text{ ft-lbs}$ as calculated above.

Therefore select Metering Pin #08 which is good for up to 176,000 lbs.

5. Select Options as per previous example.

6. Specify Oleo Bumper Model **9SBZ140-08**.
(For rear flange mount, safety cable, #08 metering pin plus any additional options from the data sheet.)

7. Maximum Bumper End Force ($EF_{B70} = 107,169 \text{ lbs.}$)

$$EF_B = \left[\frac{(119,561 \text{ ft-lbs})}{(.85) \left(\frac{15.75 \text{ in}}{12} \right)} \right] = 107,169 \text{ lbs}$$

End force at 50% speed = $EF_{B50} = (50/70)2 \times 107,169 + 54,678 \text{ lbs.}$

8. Maximum Deceleration at 50% Speed ($A_{50\%}$):

Crane 1:

$$\text{Max. dec.} = (EF_{B50}/W_{EB1}) \times g = (54,678/240,000) \times 32.2 = 7.34 \text{ ft/sec}^2$$

Crane 2:

$$\text{Max. dec.} = (EF_{B50}/W_{EB2}) \times g = (54,678/283,000) \times 32.2 = 6.22 \text{ ft/sec}^2$$

C. WORKED CRANE EXAMPLE (CASE 1. CMAA)

BRIDGE (Use the same crane data as A.)

1. Calculate maximum impact weight per side, $W_{EB} = 240,000 \text{ lbs}$ as per the above.
2. Calculate Kinetic Energy per side (KE_B) as per above, but use:

$$V_{EB} = (.4)(V_B) = (.4)(6.0 \text{ ft/sec}) = 2.4 \text{ ft/sec}$$

$$KE_B = \left(\frac{1}{2} \right) \left(\frac{240,000 \text{ lbs}}{32.2} \right) (2.4 \text{ ft/sec})^2 = 21,466 \text{ ft-lbs}$$

3. So Oleo Type 21-150 has sufficient energy capacity. Minimum stroke required to meet CMAA:

$$S_{RB} = \left[\frac{(V_{20\%})^2 (12 \text{ in})}{(2)(A_{20\%})} \right] = \left[\frac{(1.2 \text{ ft/sec})^2 (12 \text{ in})}{(2)(3 \text{ ft/sec}^2)} \right]$$

$$S_{RB} = 2.9 \text{ inches}$$

Oleo bumper Type 21-150 has $S_{AB} = 6 \text{ inches}$, so it is acceptable.

4. Select Metering Pin #08 from bumper data sheet as done previously.
5. Select options.

6. Specify Oleo Bumper Model **21SBS100-158**
(For rear flange mount, safety cable, #158 metering pin)

7. $EF_B = 50,508 \text{ lbs.}$

8. Average Deceleration at 20% speed ($A_{20\%}$):

Substitute S_{AB} for S_{RB} in equation 3 and solve for actual $A_{20\%}$:

$$A_{20\%} = 1.3 \text{ ft/sec}^2$$

(For CMAA, $A_{20\%} \leq 3 \text{ ft/sec}^2$)

TROLLEY

1. $W_{ET} = 50,000 \text{ lbs.}$
2. $V_{ET} = (.5)(V_T) = (.5)(3.33 \text{ ft/sec}) = 1.61 \text{ ft/sec}$
 $KE_T = 2,165 \text{ ft-lbs}$

Proceed as for CMAA bridge bumpers, but use:

$$A_{33\%} \leq 4.7 \text{ ft/sec}^2$$

Select Oleo Bumper Model **21SBS100-055**.

$$EF_{T50\%} = 15,282 \text{ lbs and } A_{33\%} = 3.1 \text{ ft/sec}^2$$

1. AIST TECHNICAL REPORT #6, 2005

“Bumpers Provisions in the design of the runway and the design of the runway stops shall consider the energy absorbing or storage device used in the crane bumper. The device may be nonlinear (e.g. hydraulic bumpers) or a linear device such as a coil spring.

The maximum deceleration rate for both bridge and trolley shall not exceed 16 fps^2 at 50% of the full load rated speed (full load rated speed shall be used unless adequate information is supplied by owner to determine the actual attainable maximum speed). Additionally, bumpers shall be capable of absorbing the total energy at 100% full load rated speed.

Between cranes or trolleys (if two trolleys are located on one bridge) bumpers shall be capable of absorbing the energy from 70% of full load rated speed of both cranes or trolleys traveling in opposite directions, or the energy from 100% of full load rated speed of either crane or trolley, whichever is the greatest.

The design of all bumpers shall include safety cables to prevent parts from dropping to the floor.

For computing bridge bumper energy, the trolley shall be placed in the end approach which will produce the maximum end reaction from both bridge and trolley. This end reaction shall be used as the maximum weight portion of the crane that can act on each bridge bumper. The energy absorbing capacity of the bumper shall be based on power-off and shall not include the lifted load if free to swing. Bridge bumpers shall have a contact surface of not less than 5 in. in diameter, be located on the rail centerline and mounted to provide proper clearance when bumpers of two cranes come together and both are fully compressed.

Note: The building and end stops shall be designed to withstand those forces of the fully loaded crane at 100% rated speed (power off). Please refer to AIST Technical Report No. 13.”

(From Association for Iron & Steel Technology Report #6)

2. CMAA SPECIFICATION #70, 2004

“Bridge bumpers - Have energy absorbing (or dissipating) capacity to stop the crane when traveling with power off in either direction at a speed of at least 40 percent of rated load speed.

Be capable of stopping the crane (not including load block and lifted load unless guided vertically) at a rate of deceleration not to exceed an average of 3 feet per second per second when traveling with power off in either direction at 20 percent of rated load speed.

Be so mounted that there is no direct shear on bolts upon impact.

Bumpers shall be designed and installed to minimize parts falling from the crane in case of breakage or loosening of bolted connections.

It is the responsibility of the owner or specifier to provide the crane manufacturer with information for bumper design. Information necessary for proper bumper design includes:

- Number of cranes on runway, bridge speed, approximate weight, etc.
- Height of runway stops or bumper above the runway rail.
- Clearance between cranes and end of run-way.

Runway stops are normally designed and provided by the owner or specifier and are located at the limits of the bridge travel and engage the full surface of the bumper.

Runway stops engaging the tread of the wheel are not recommended.

Trolley Bumpers - Have energy absorbing (or dissipating) capacity to stop the trolley when traveling with power off in either direction at a speed of at least 50 percent of rated load speed.

Be capable of stopping the trolley (not including load block and lifted load unless guided vertically) at a rate of deceleration not to exceed an average of 4.7 feet per second per second when traveling with power off in either direction at 1/3 of rated load speed.

Be so mounted that there is no direct shear on bolts upon impact.

Bumpers shall be designed and installed to minimize parts falling from the trolley in case of breakage.

Trolley stops shall be provided at the limit of the trolley travel, and shall engage the full surface of the bumper.

Trolley stops engaging the tread of the wheel are not recommended.”

(From Crane Manufacturer's Association of America Spec. #70)

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