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Case Study

Incline Impact: A Case Study

S. Malasri, T. Podesta, R. Moats, T. Waddell, D. Duckworth, T. Ayesh and R. W. Brown

Gadomski School of Engineering, Christian Brothers University, 650 E. Parkway S., Memphis, TN 38104, USA

Correspondence should be addressed to Siripong Malasri, *pong@cbu.edu*

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Abstract An incline impact test can be used as a shock test in lieu of a drop test in several test protocols, including ISTA Procedure 1A [1]. Some test protocols, such as ISTA Procedure 1E [2], only allow for an incline impact test and horizontal impact test. In this case study, a graph was developed for a 500-lb impact tester at Christian Brothers University (CBU) Packaging Laboratory. It determines sliding platform location on the incline for a given packaged-product weight to meet the impact velocity recommended by the International Safe Transit Association (ISTA). One station of the platform location higher than the station obtained from the graph is recommended to ensure the meeting of ISTA recommended impact velocity.

It is well known that weight is not used in impact velocity of a free fall drop. However, this case study shows that weight contributes to impact velocity of an incline impact test. It contributes to the rolling friction. A heavier weight yields a smaller coefficient of rolling friction (μ_k), which results in a higher impact velocity. The coefficient of rolling friction for CBU's incline impact tester can be computed from $\mu_k = -9^{-5}w + 0.1092$, where *w* is the total weight of the sliding platform and packaged product.

Keywords *Incline Impact Test; Rolling Friction; Impact Velocity*

1. Introduction

Incline impact test is a shock test method. A packaged product is placed on a sliding platform. The sliding platform is positioned at a location on the incline plane, which tilts 10 degrees from the horizontal plane. The sliding platform with the packaged product on the top slides down the incline by gravity. It hits a back rest at the end of the incline. Figure 1 shows the 500-lb incline impact tester at CBU's Packaging Laboratory used in this case study.

In a more common free-fall drop test, an impact velocity (v_f) can be determined from $v_f = \sqrt{2gh}$, where g = *32.2 ft/s*^{2} and h = drop height in feet. The equation is independent from the packaged-product weight to drop. Test protocols, such as ISTA 1A, specify drop heights for different ranges of packaged-product weight. However, test protocols for incline impact test specify impact velocity for different ranges of packaged-product weight, such as 8 ft/s for packaged-product weights from 61 to less than 100 lb or 6.6 ft/s for weights from 100 lb to less than 150 lb [1].

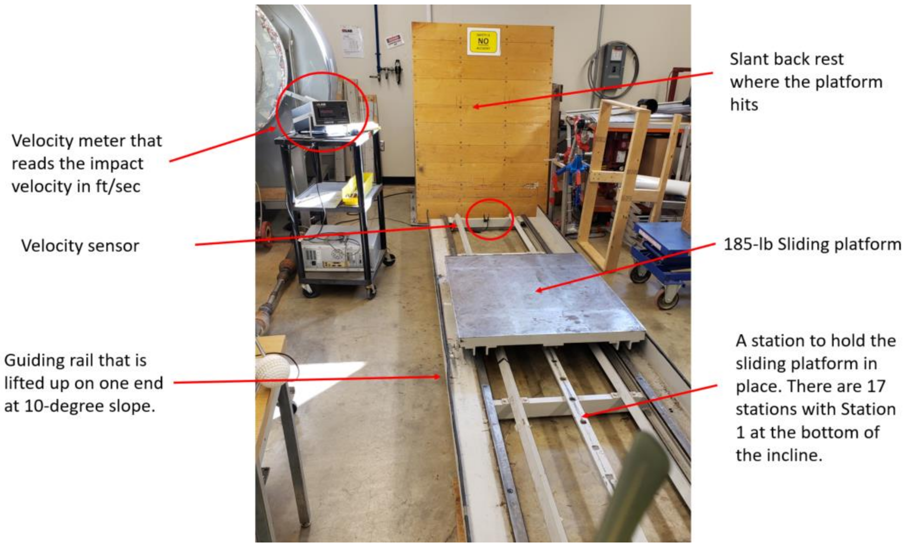

Figure 1: *500-lb Incline Impact Tester Used in This Study*

The goals of this study were:

- To develop a chart that can be used to determine the position of the sliding platform on the incline for a given packaged-product weight to result in a desired impact velocity.
- To show the effect of weight on the impact velocity through the rolling friction between the sliding platform and the guiding rail.

2. Materials and Methods

When an object rolls downward on an incline plane without rolling friction from an at-rest position on the incline, the following equation from physics [3] can be used:

$$v_f^2 - v_i^2 = 2aS$$

Where v_f is the final velocity, v_i = initial velocity = 0, a = acceleration along the incline plane, and S = distance travelled. The acceleration, a, on a 10-degree incline plane can be written in term of g, which is 32.2 ft/s^2:

$$a = g \sin 10^0$$

The final velocity, which is the impact velocity, can then be written as:

$$v_f = 3.34\sqrt{S}$$

The equation can be rearranged to determine the distance travelled, which is the position of the sliding platform, for a desired impact velocity:

$$s = v_f^2/11.156$$

However, if rolling friction is included, the impact velocity becomes:

$$v_f = \sqrt{2g(sin\,\theta - \mu_k cos\theta)S}$$

For $\theta = 10^0$ and $g = 32.2\ {ft}/{s^2}$, the coefficient of rolling friction becomes:

$$\mu_k = \frac{\left(11.206 - \frac{v_f^2}{s}\right)}{63.434}$$

Different weights of packaged product were used in this case study; 0 lb (no packaged product on the sliding platform), 50 lb, 100 lb, and 150 lb. Five incline impact tests were performed for each weight at each of the 17 positions or stations on the incline. Impact velocity was measured for each test and an average of five incline impact tests was used. Since the data was collected from a real test, thus rolling friction was built in.

3. Results

Table 1 shows an example of impact velocity data collected for packaged-product (or box) weight of 50 lb. It should be noted that these impacts were the result of total weight, i.e., box weight + sliding platform weight (185 lb). Similar data was collected for 0-lb, 100-lb, and 150-lb boxes. They were plotted in Figure 2 with Travel Distance on the x-axis. It is more practical to have the graph plotted with Station Number on the x-axis, as shown in Figure 3.

The following was observed:

- Heavier weight produced higher impact velocity.
- For the weights used in this study, the maximum impact velocity this incline impact tester could produce was about 8.6 ft/s.

Table 1: *Impact Velocity from Incline Impact Tests of 50-lb Box Weight*

			Impact Velocity (ft/s)					
Box Wt. (lb)	**Station**	***Travel Dist (ft)***	1	2	3	4	5	***Avg***
50	1	*3.33*	4.18	4.19	4.19	4.18	4.18	*4.18*
	2	*3.83*	4.49	4.58	4.58	4.47	4.58	*4.54*
	3	*4.33*	4.95	4.85	4.85	4.85	4.85	*4.87*
	4	*4.83*	5.16	5.06	5.16	5.06	5.07	*5.10*
	5	*5.33*	5.39	5.39	5.51	5.51	5.51	*5.46*
	6	*5.83*	5.65	5.78	5.64	5.64	5.65	*5.67*
	7	*6.33*	5.93	6.06	5.92	6.06	5.92	*5.98*
	8	*6.83*	6.22	6.07	6.06	6.06	6.22	*6.13*
	9	*7.33*	6.40	6.39	6.39	6.39	6.56	*6.43*
	10	*7.83*	6.56	6.75	6.75	6.73	6.56	*6.67*
	11	*8.33*	6.93	6.93	6.93	6.93	6.93	*6.93*
	12	*8.83*	6.94	7.14	7.14	7.14	7.14	*7.10*
	13	*9.33*	7.59	7.36	7.36	7.36	7.36	*7.41*
	14	*9.83*	7.59	7.59	7.59	7.59	7.59	*7.59*
	15	*10.33*	7.82	7.84	7.59	7.82	7.84	*7.78*
	16	*10.83*	8.07	8.09	7.82	8.09	7.84	*7.98*
	17	*11.33*	8.11	8.09	8.09	8.09	8.09	*8.09*

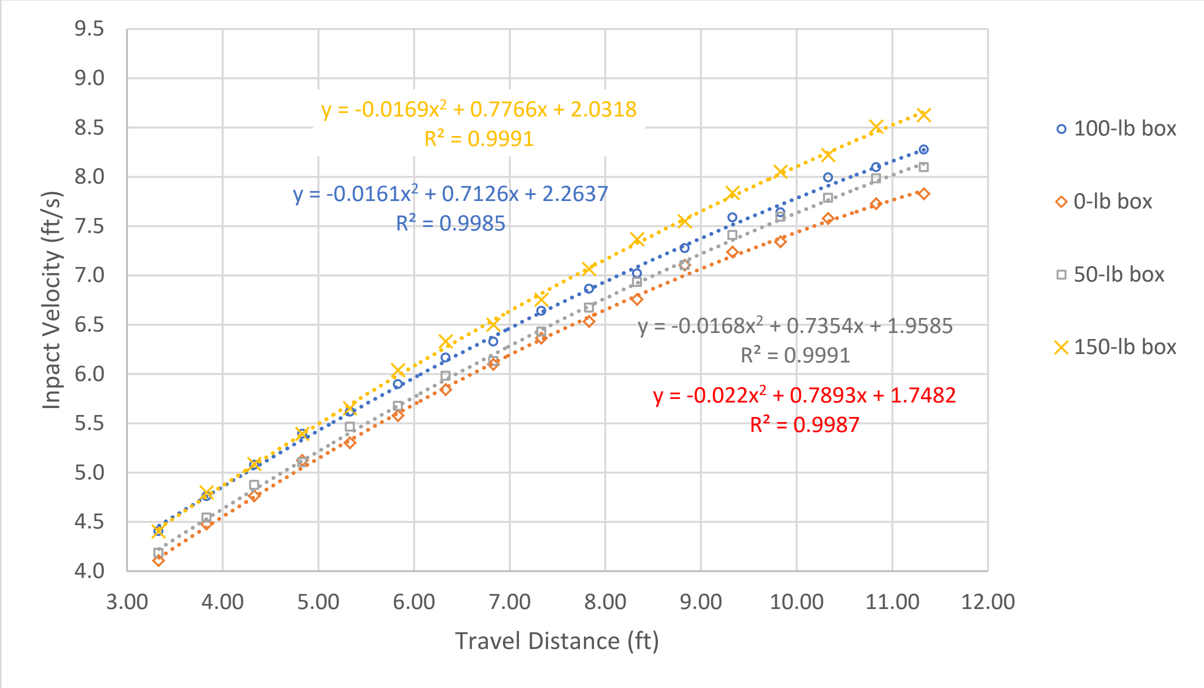

Figure 2: *Impact Velocity vs Travel Distance*

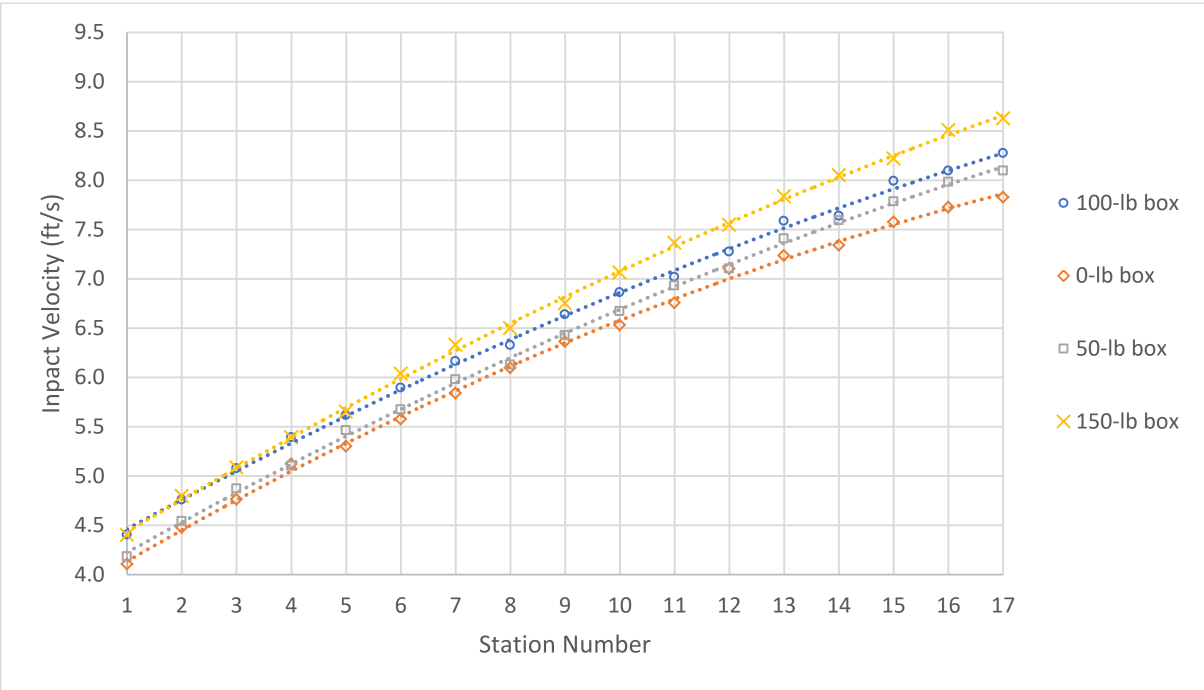

Figure 3: *Impact Velocity vs Station Number*

A validation was performed using box weights of 0 lb, 50 lb, 75 lb, 100 lb, 125 lb, and 150 lb, as shown in Table 2. For each box weight, a desired impact velocity was determined from ISTA Procedure 1A test protocol. The validation of 0-lb box and 50-lb box could not be performed due to the limit of this specific incline impact tester, i.e., its inability to reach 13 ft/s for 0-lb box (empty sliding platform) and 10 ft/s for 50-lb box. For 75-lb, 100-lb, 125-lb, and 150-lb boxes, two stations were used; (1) the station obtained from the graph (with rounding up to the whole station number) and (2) one station higher than the one from the graph.

Table 2: *Validation*

Box Weight (lb)	ISTA Velocity (ft/s)	Station Number	Distance (ft)	Impact Velocity (ft/s)						% of ISTA
				1	2	3	4	5	Avg	
0	13	N.A.								
50	10	N.A.								
75	8	16	10.83	7.82	7.84	7.84	7.84	7.82	**7.83**	***-2.10***
75	8	17	11.33	8.07	8.07	8.05	8.07	8.07	**8.07**	0.83
100	6.6	10	7.83	6.93	6.93	6.94	6.75	6.75	**6.86**	3.94
100	6.6	11	8.33	7.14	7.14	6.94	6.93	6.94	**7.02**	6.33
125	6.6	9	7.33	6.40	6.56	6.40	6.40	6.40	**6.43**	***-2.55***
125	6.6	10	7.83	6.73	6.92	6.92	6.92	6.72	**6.84**	3.67
150	6.6	9	7.33	6.75	6.75	6.75	6.75	6.76	**6.75**	2.30
150	6.6	10	7.83	7.15	6.94	7.14	7.14	6.94	**7.06**	7.00

The station number obtained from the graph shown in Figure 3 yields impact velocity lower than ISTA impact velocity in two validation cases, i.e., 75-lb box at Station 16 and 125-lb box at Station 9. Thus, it is recommended that one higher station number should be used. This would give a more conversative result.

The coefficient of rolling coefficient can be determined from the equation below, which was also mentioned earlier:

$$\mu_k = \frac{\left(11.206 - \frac{v_f^2}{s}\right)}{63.434}$$

The coefficients of rolling friction were determined using the above equation and data as shown in Table 3 below for the 50-lb box case.

Coefficients of rolling friction for 0-lb box, 100-lb box, and 150-lb box were determined the same way. They are summarized in the first two columns of Table 4. Since total weight, not only box weight, affects friction, thus 185-lb sliding platform weight was added to each box weight, as shown in the third column of Table 4. A graph was plotted for “Total Weight” versus “Coefficient of Rolling Friction” as shown in Figure 4. A linear trendline was used and a trendline equation was generated for finding the coefficient of rolling friction, μ_k, for a given total weight, *w* in lb.

$$\mu_k = -9^{-5}w + 0.1092$$

The last column of Table 4 contains estimated coefficients of rolling friction computed from this trendline equation. Coefficient of rolling friction for railroad steel wheel on steel rail is between 0.0010 to 0.0024 [4], which is much lower than 0.07+ to 0.09+ from this study. This is because a railroad weight is much higher than the total weight used in this study. As shown in Figure 4, heavier weight yields smaller coefficient of rolling friction. Thus, a 1,200-lb total weight was added to Table 4 to show that the coefficient could go down to around 0.001. Unfortunately, the incline impact tester used in this study has a maximum payload capacity of 500 lb. Thus, the coefficient of rolling friction for the total weight of 1,200 lb cannot be verified.

Table 3: *Determination of Coefficient of Rolling Friction*

Box Weight (lb)	Station Number	Travel Distance (ft)	Avg Impact Velocity (ft/s)	Coefficient of Rolling Friction
50	1	3.33	4.18	0.0939
	2	3.83	4.54	0.0919
	3	4.33	4.87	0.0904
	4	4.83	5.10	0.0918
	5	5.33	5.46	0.0885
	6	5.83	5.67	0.0897
	7	6.33	5.98	0.0877
	8	6.83	6.13	0.0901
	9	7.33	6.43	0.0879
	10	7.83	6.67	0.0871
	11	8.33	6.93	0.0858
	12	8.83	7.10	0.0867
	13	9.33	7.41	0.0840
	14	9.83	7.59	0.0843
	15	10.33	7.78	0.0843
	16	10.83	7.98	0.0839
	17	11.33	8.09	0.0855
	Avg Coefficient of Rolling Friction =			***0.0878***

Table 4: *Compilation of Coefficient of Rolling Friction*

Box Weight (lb)	Coefficient of Rolling Friction	Total Weight (lb)	Estimated Coefficient of Rolling Friction from Trendline Equation
0	0.0913	185	0.0926
50	0.0878	235	0.0881
100	0.0824	285	0.0836
150	0.0774	335	0.0791
		1200	*0.0012*

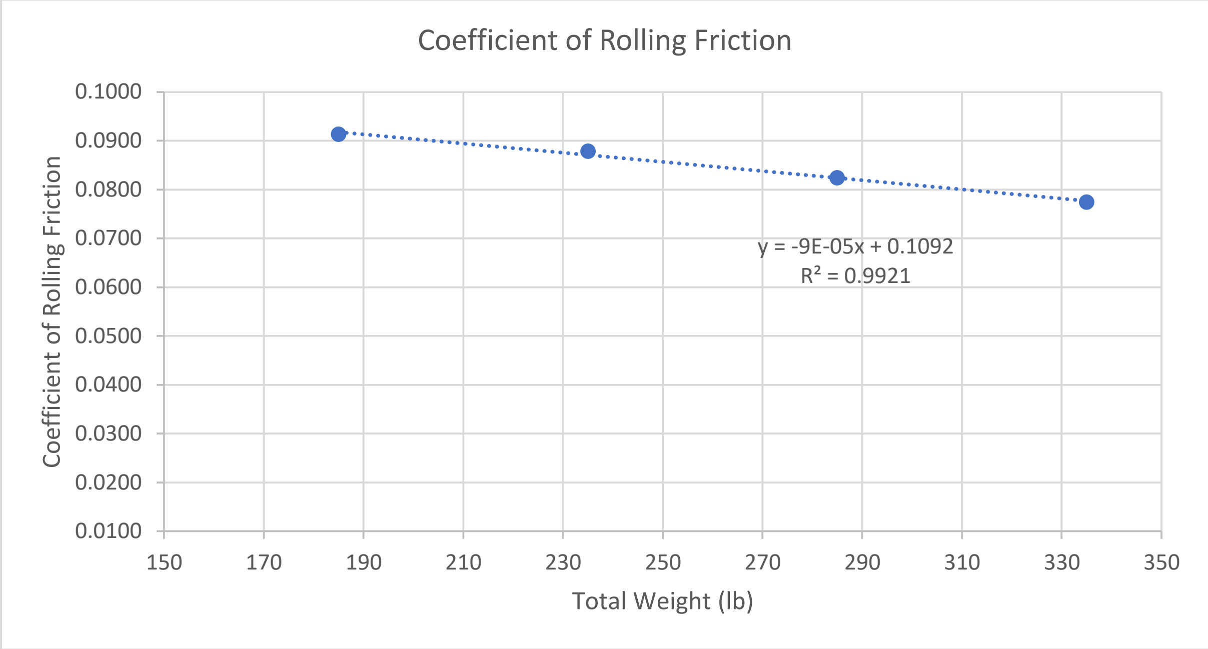

Figure 4: *Coefficient of Rolling Friction Trendline Equation*

4. Conclusions

From this case study, the following general conclusions can be made:

- Rolling friction affects the impact velocity of an incline impact test.
- Weight contributes to the rolling friction.
- Heavier the weight is, smaller the coefficient of rolling friction occurs.
- Heavier the weight is, higher the impact velocity is resulted.
- A specific chart can be developed for an incline impact tester to determine the location of the sliding platform.

The following conclusions can also be made specific to the 500-lb incline impact tester used in this study:

- To meet ISTA impact velocity recommendation, it is recommended that the next higher station from the station obtained from graph is used.
- Coefficient of rolling friction is calculated from $\mu_k = -9^{-5}w + 0.1092$.

Acknowledgement

The incline impact tester used in this study was donated to CBU Packaging Laboratory by FedEx Packaging Laboratory.

References

[1] *Procedure 1A, Packaged-Products 150 lb (68 kg) or Less*, International Safe Transit Association, 2014.

[2] *Procedure 1E, Unitized Loads of Same Product*, International Safe Transit Association, 2014.

[3] S. Holzner, *Finding the Velocity of an Object Moving along an Inclined Plane*. *https://www.dummies.com/education/science/physics/finding-the-velocity-of-anobject-moving-along-an-inclined-plane/ (Accessed on February 18, 2021)*

[4] *Rolling Resistance*, Wikipedia. *https://en.wikipedia.org/wiki/Rolling_resistance (Accessed on February 19, 2021)*