# Ramp design for roll-handling systems

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**ABSTRACT** *Roll handling—from the production winder through wrapping and finishing operations to storage and shipping—involves the application of steel or concrete ramps. To date, these ramps have been designed almost solely by empirical methods. This paper discusses ramp uses and applications, materials of construction, and safety considerations. The physics of roll movement is also examined to develop a theoretical basis for ramp design. The resultant model was tested in the field and in the laboratory. The results show that roll velocity and displacement can be predicted with confidence.*

**KEYWORDS**
Construction
Control equipment
Control systems
Materials handling
Mathematical analysis
Rolls
Safety
Sensors

In most roll-handling operations, at some point, the roll travels down an inclined plane on its bilge in a direction perpendicular to the roll axis. In some mills, operators find the slope of the ramp insufficient to initiate rolling or to prevent rolls from stalling. This condition often requires arduous, if not unsafe, manual effort on the part of the operator to move the roll. In other mills, slopes are too steep, causing rolls to move at high velocities, endangering personnel and risking damage to both rolls and equipment.

With such disparity in performance, it is fair to ask how ramp slopes for roll transport are determined. To date, such ramps have been designed almost solely by empirical methods. The work presented in this article was undertaken in an attempt to develop an analytical method to approach the task of ramp design. The method presented here provides a deeper insight into roll behavior on an inclined plane. The discussion also focuses on ramp applications and on safety issues that must be considered when designing ramps for a roll-handling system.

## Why ramps are used

Designers of materials-handling systems are guided by two axioms.

1. The system that handles the material the least is the best.
2. The primary design criterion in any roll-handling system is control of the roll at all times.

The use of ramps in a roll-handling system is a good way of applying both axioms. Ramps take advantage of a roll's shape and use gravity to transport the roll, thereby eliminating the need for complex, expensive equipment. Appropriate design of a ramp's slope allows operational control to be maintained when the roll is in motion. Through strategic placement of successive roll stops along the ramp, rolls can be accumulated, metered, and/or transported over considerable distances that would otherwise require more expensive equipment and occupy more floor space.

Ramps are an effective means of changing the elevation of a roll. For instance, a roll traveling on a conveyor that is flush with the floor can be elevated by a hydraulic kicker/lifter to the high end of a ramp. The roll can then travel down the ramp to another conveyor or to another operation at a higher elevation than the original conveyor.

## Materials of construction

The ramps in a roll-handling system are generally made of concrete or steel. Steel ramps at the floor level have access pits beneath them, while elevated steel ramps provide easy access for maintenance. The type of ramp is usually based on such constraints as existing conditions in the area where the ramp is to be installed. This will be discussed in greater depth in the following section on ramp applications.

## Ramp applications

### Winder discharge

Most mills use salvage winders in addition to paper machine production winders. Some salvage winders have ramps at their discharge, but almost all production winders use some type of ramp to assist in transporting the rolls from the winder, through sorting or separation, barcoding, stenciling, and on to a conveyor transport system. The type of ramp used depends on the type of winder involved, since single-drum and two-drum machines have very different types of discharge systems.

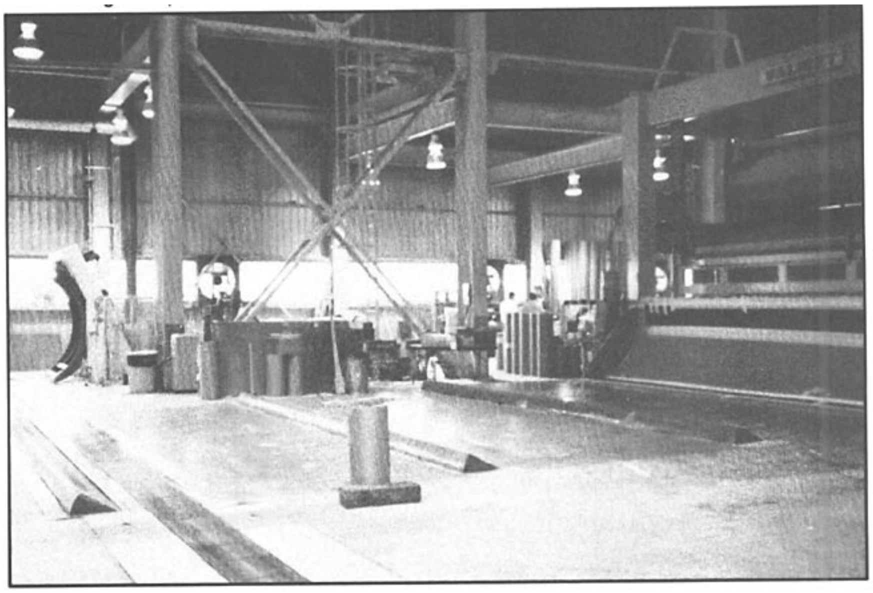
A two-drum winder ejects a roll set from the front of the winder. In most mills, a lowering table carries the wound roll to the floor. The lip of the lowering table, on which the roll rests when lowered, is itself a steel ramp with a slope sufficient to ensure that the roll will rotate off the lip by gravity and onto a fixed ramp of steel or concrete. It is usually concrete because of its size, its close proximity to the floor, and its quieter performance.

The slope of a ramp is a crucial design criterion. It should be obvious why it is important to install the correct slope when pouring large quantities of concrete. Concrete slopes should be installed by skilled craftsmen to minimize "float" and ensure smooth, uniform surfaces of the specified slope.

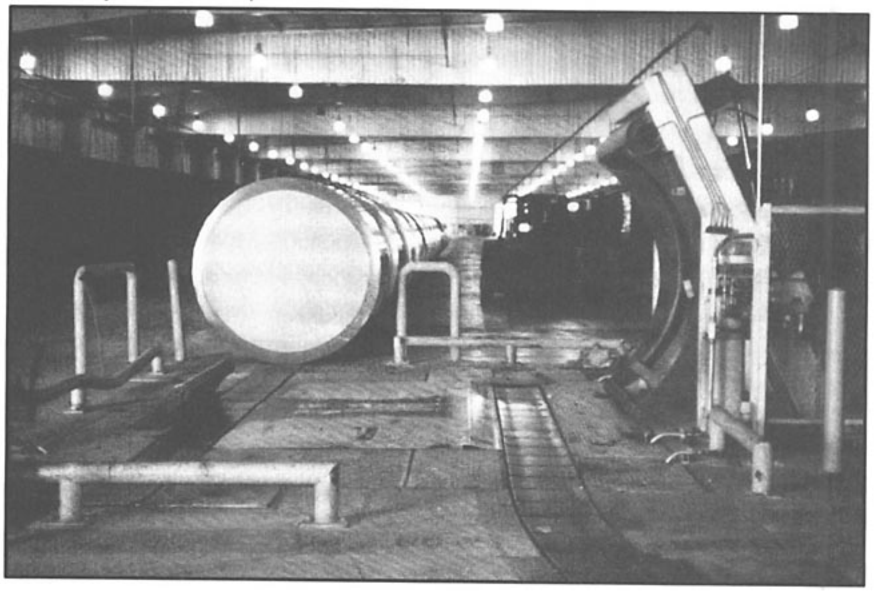
**Figure 1** illustrates a typical two-drum winder discharge ramp complete with retractable plate stop, segregated roll stops, in-floor conveyor at the bottom of the ramp, and roll-arresting retractable bumper. Generally, winder discharge ramps should have sufficient slope so that the particular grade of paper rolls being handled will begin rolling unassisted and continue rolling until arrested by some mechanical means.

However, a roll may continue to accelerate down a ramp. How great a velocity should it be allowed to attain? Roll velocity must be controlled for both safety and protection of roll quality and equipment. One of the major roll-handling equipment manufacturers allows up to three feet per second as the maximum velocity a roll should be allowed to reach (*1*). However, certain paper grades and manufacturing areas may require a lower velocity. Velocity is controlled by a combination of ramp slope and the distance a roll is allowed to travel before being arrested by a roll retarder, roll stop, or bumper. Data on these physical properties is presented under the heading "Physics of roll movement."

**1.** Discharge ramp from two-drum winder



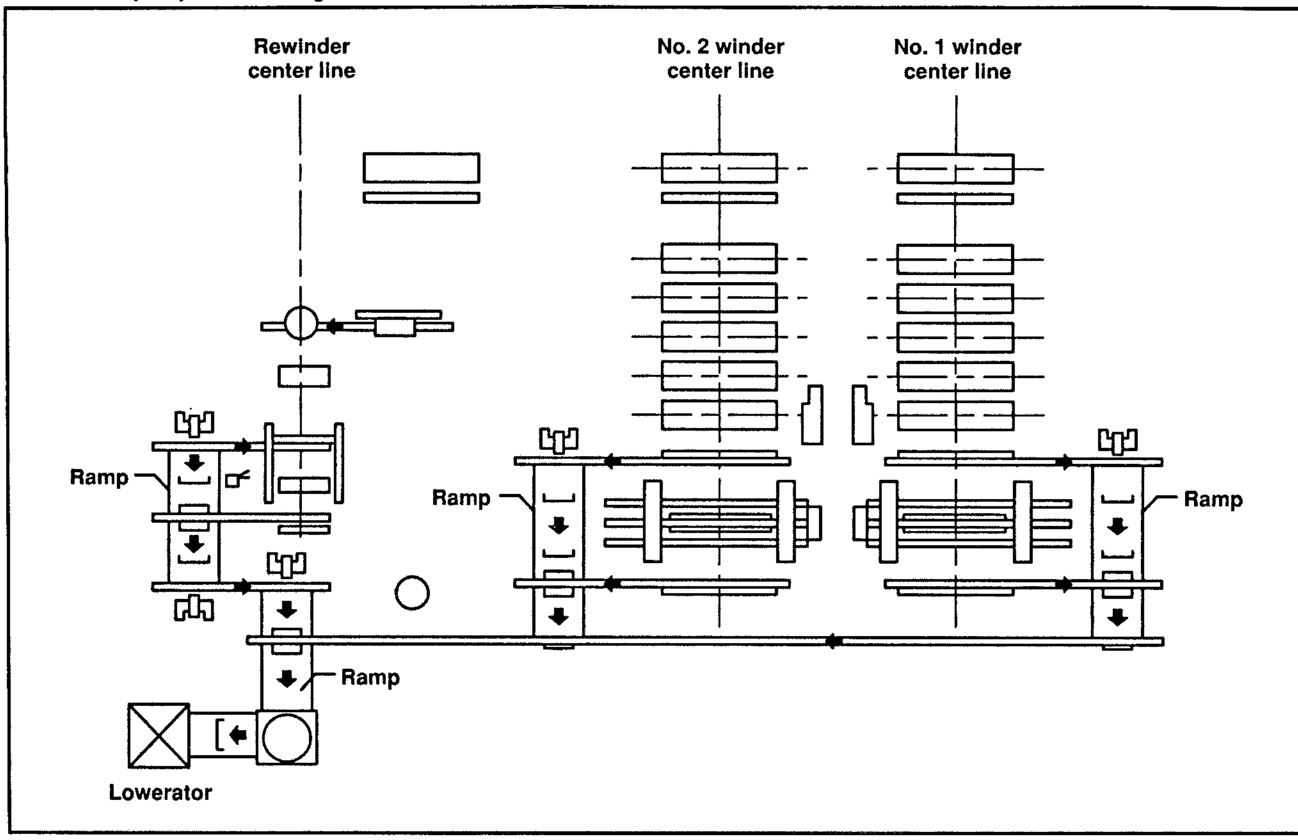
**3.** Conveyor transfer ramp



A single-drum winder discharges rolls from both the front and back of the winder, where conveyors (usually steel slat) receive the discharged roll. These conveyors are used in conjunction with a steel ramp located to one side of the winder. The ramp has roll stops for metering the rolls onto a roll transport conveyor system to finishing operations such as strapping, wrapping, heading, etc.

On single-drum winders, rolls are either released from core chucks onto the ramps or released and ejected onto lowering tables that carry them down to the ramps. In either case, the rolls must initiate rolling by gravity and continue onto the main transport conveyor. By nature of the design of this type of winder, the rolls are already separated and, therefore, do not require segregated roll stops to allow application of barcodes, stenciling, etc., by the operator. The advantage of separating winder conveyors from the main transport conveyor is that rolls can be automatically fed into the system without further operator control. A typical single-drum winder

**2.** Roll-conveyor system for a single-drum winder




arrangement is illustrated in **Fig. 2**.

**Conveyor transfer**

Ramps also provide a means of transferring rolls from one conveyor to another when the two conveyors are parallel. If the distance between the conveyors is great (more than 50 ft), the most frequently used transfer system utilizes turntables at each end and an intermediate conveyor at right angles to the two parallel conveyors. However, ramps can be used for shorter distances or when intermediate functions, such as measurement of roll width and diameter, are carried out between the two conveyors.

Such ramps can be constructed of concrete or steel. Concrete ramps are seldom installed to the same tolerances (slope, width, smoothness, etc.) as manufactured steel ramps. In either case, pits (for first-floor operations) and floor openings (for second-floor operations) are required for cylinders and mechanisms that operate roll stops and other ramp equipment. Raised steel ramps generally reduce floor-penetration requirements. **Figure 3** illustrates a conveyor transfer ramp.

Ramp width is another design consideration. The trend today is to design ramps that extend to the maximum roll width. This practice apparently is based on the belief that passage of a wide roll over a narrow ramp creates a heavy overhang that can damage the roll.

Although certain grades of paper may justify the use of full-width ramps, one major supplier of roll-handling equipment has found that they usually are not required (*1*). For several years, this manufacturer has been furnishing ramps that are narrower than the widest rolls. The specific ramp width is usually determined by rule-of-thumb techniques unique to a given manufacturer, in much the same way that ramp slopes have been determined to date.

Full-width ramps may be the safe way to go when there is no prior experience or opportunity to test. However, before automatically specifying full-width ramps, consider that this option can unnecessarily increase capital costs because of

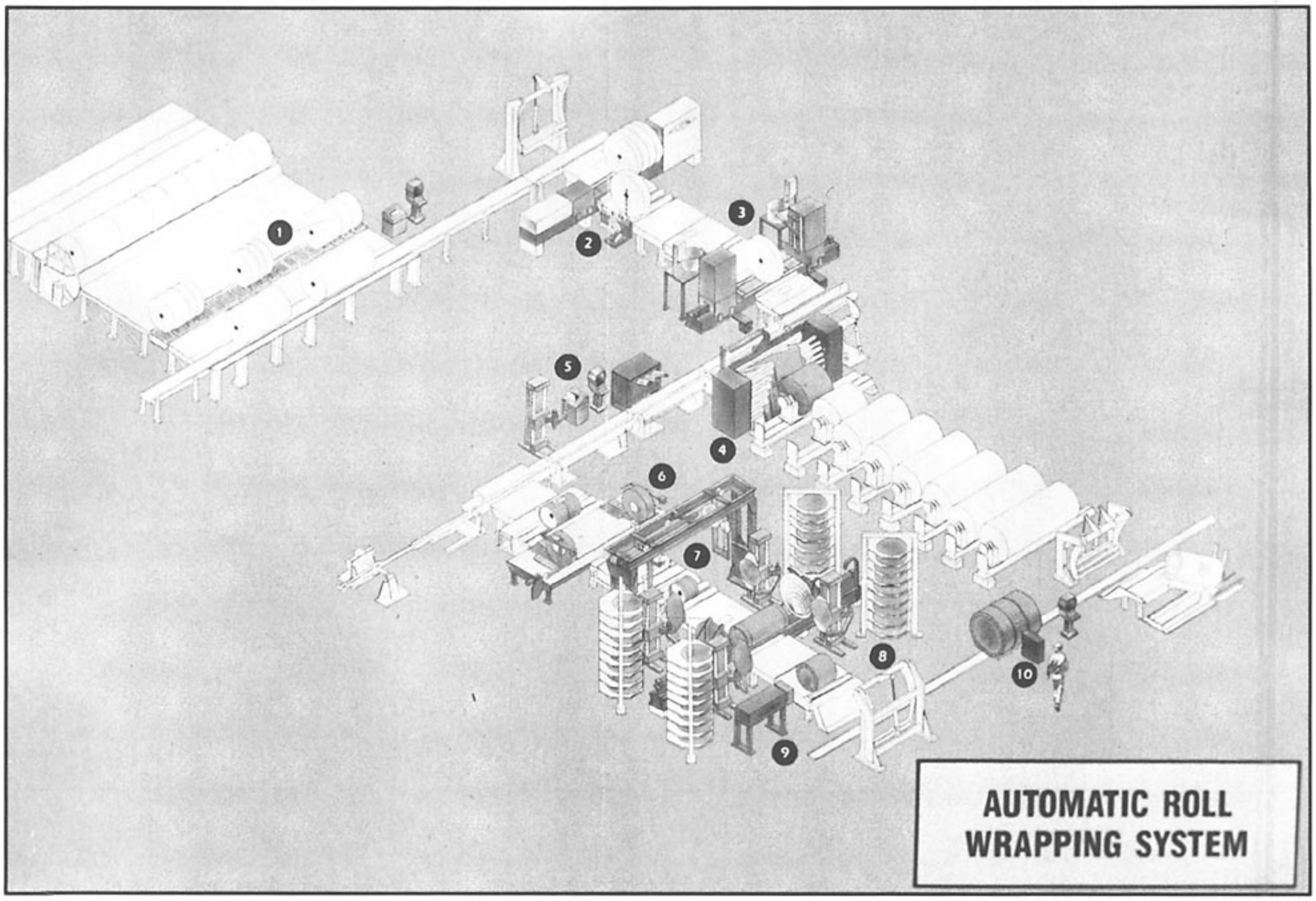
- Larger surface areas, which must be smoothed to a given tolerance
- More surface material
- Additional support structure.

**Lowerator discharge**

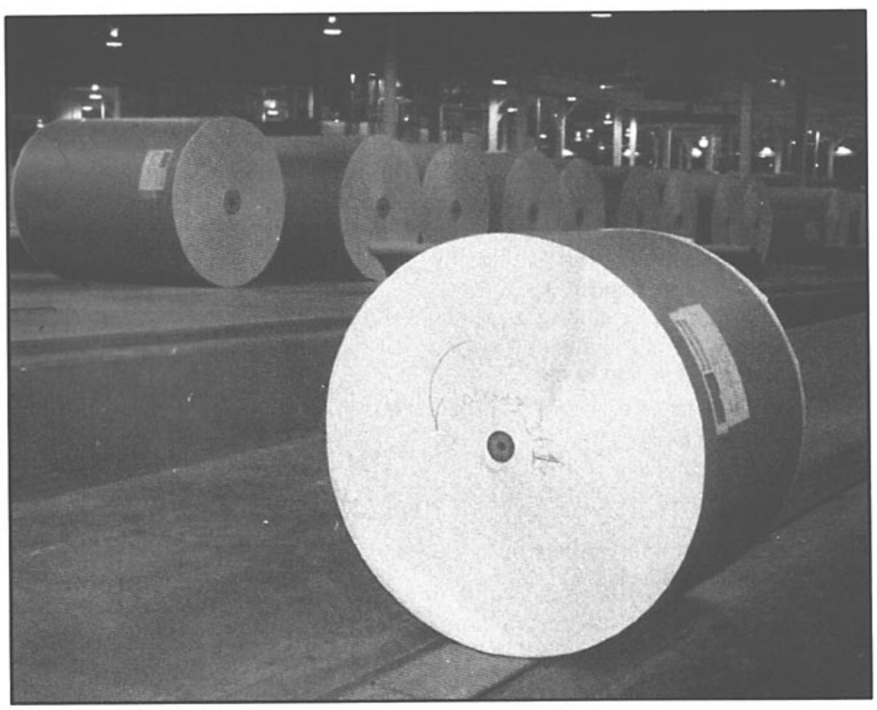
Rolls are usually lowered vertically from the production area or from the finishing room to the ground floor for shipping or storage by means of some type of mechanical or hydraulic roll lowerator. At the ground floor, the roll is most often discharged onto a ramp, where it is temporarily held before being metered onto another roll conveyor/handling system. Some lowerators are designed to discharge from either of two sides, adding flexibility to the handling system.

It must be a point of careful consideration, however, that rolls always be rolled in the direction of wind, unless they have already been strapped. Backward rolling will loosen outer layers of the roll, causing telescoping, damage, and/or poor appearance. Rolls wrapped in lieu of strapping should particularly avoid backward rolling. Certain paper grades can tolerate enough reverse rolling to allow one or two backward kicks onto a turntable, or the like, to facilitate a layout requirement. In

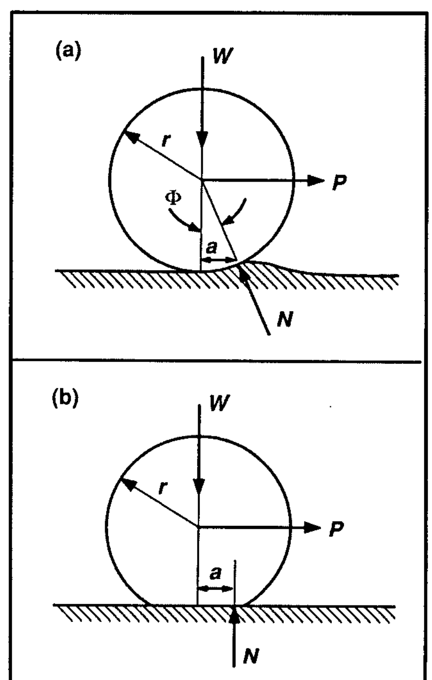
**4.** Automatic roll-wrapping system



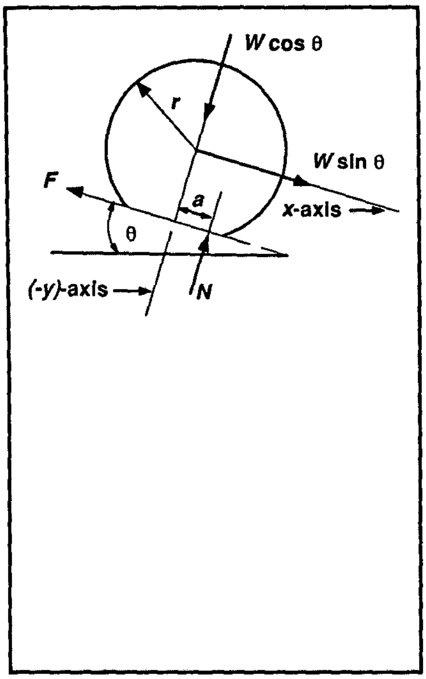

**5.** Sorting ramp



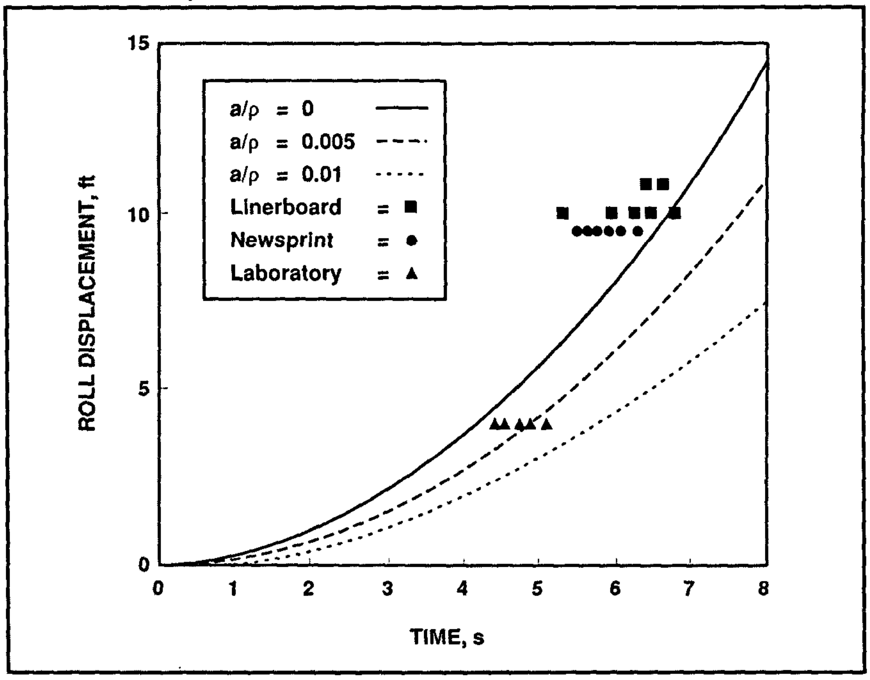
**6.** Rolling resistance models (a) Shames (3) and (b) Moore and Stephens. $W$ = weight, $P$ = applied force, $N$ = normal reaction force, $r$ = roll radius, $a$ = distance of offset for $N$.



7. Free-body diagram of roll on inclined plane.




8. Roll displacement as a function of time. The three curves represent predicted results for different values of a/ρ. Data points depict results obtained in the field (linerboard and newsprint) and in the laboratory.




general, though, backward rolling should be avoided.

### Wrapping systems

Modern, low-profile, high-speed kraft wrappers and stretch wrappers are usually mounted on elevated steel platforms. This configuration provides easier access for maintenance, and the cost of erecting the steel support framework is less than the foundation work that would be needed for a floor-level installation. Lifting scoops—fed from and discharging to ramps—are used at entry and discharge, where rolls are raised from or lowered to the floor.

Rolls to be wrapped are raised and released from the lifting scoop to roll down a ramp where they are bar-code scanned, centered, checked for proper width and diameter, and weighed at successive stations until the roll is bumper-arrested upon a "walking beam" indexing conveyor.

The indexing conveyor carries the roll through wrapping, end banding, labeling, and color marking before a kicker discharges the roll onto another ramp. On the new ramp, the roll travels down through progressive stations, where it can be momentarily stopped for such operations as inside head application, crimping, outer heading, and end labeling.

On both the initial identification-station ramp and the final applications ramp, the roll moves from station to station at controlled rates. The roll must move fast enough to achieve the desired cycle rate but still be handled without damage or unsafe movement. Today's wrappers have 20-s cycle rates and require quick, precise roll movement. An example of a typical modern kraft wrapping system is shown in **Fig. 4**.

### Roll-sorting decks

Because multiple orders are usually run on a single winder, some type of roll sorting is required to group rolls that belong together for storage and shipping. Also, rolls from multiple wrapper operations are directed to a central sheeting or storage/shipping area, where rolls for a given order must be consolidated. Once sorted, rolls can be sent to devices such as a roll upender, where they can be grouped for stacking and handling. Stacking prior to pickup by clamp truck increases the efficiency of handling operations.

Roll sorting is accomplished by three basic means

1. Sorting ramps
2. Pairing pockets
3. Sorting belts (or belt pockets)

Of these three, the sorting ramp is the most flexible (*2*). The sorting ramp can be programmed to automatically feed rolls in an order that properly groups them. Since sorting ramps require much surface area, it is imperative that the correct slope be determined prior to construction. **Figure 5** illustrates a typical sorting-ramp operation.

## Physics of roll movement

Unattended paper rolls do not maintain uniform motion along a horizontal surface. This indicates that some type of resistance to rolling must be present. Shames (*3*) developed a model of rolling resistance by assuming that a hard or rigid roll causes a deformable surface to bunch up in front of the roll. As illustrated in **Fig. 6(a)**, the deformation of the surface allows the normal reaction force ($N$) between the roll and the surface to rotate through an angle $\phi$. This rotation in the direction of the reaction results in a component of force that opposes motion.

Paper rolls are usually much softer than the surfaces upon which they are rolling. In fact, for all but the hardest rolls, deformation of the roll is visually observed. Given this fact, we developed an alternative model of rolling resistance, presented in **Fig. 6(b)**. In this model, it is assumed that the surface remains undeformed, while the roll flattens over the region of contact. This flattening allows the normal reaction to be offset from the center of the roll by a distance $a$, resulting in an opposition to motion.

#### Roll velocity and displacement

Equations for the velocity and displacement of the paper roll in Fig. 6(b) can be developed by considering the forces acting on the roll depicted in **Fig. 7**.

Choosing the coordinate system such that the $x$-axis is parallel to the surface of the ramp, the acceleration of the roll down the ramp can be written as

$$d^2x/dt^2 = (g \sin\theta) - F/m \qquad (1)$$

where

$d^2x/dt^2$ = acceleration of the roll down the ramp

$g$ = standard acceleration of gravity

$\theta$ = angle of ramp slope

$F$ = traction force between the roll and the ramp

$m$ = mass of the roll

The summation of forces in the $y$-direction implies that

$$(mg \cos\theta) - N = 0 \qquad (2)$$

while the moment of momentum about the center of the roll can be written as

$$I\alpha = F\rho - Na \qquad (3)$$

where

$N$ = reaction force normal to the ramp

$I$ = moment of inertia of the roll mass

$\rho$ = radius from the roll's center to the ramp

$a$ = distance $N$ is offset from $y$-axis

$\alpha$ = angular acceleration of roll down the ramp.

The remaining required equation is the kinematic relationship described in Eq. 4.

$$\alpha = (1/\rho)\,(d^2x/dt^2) \qquad (4)$$

Substitution of Eqs. 2 and 4 into Eq. 3 yields Eq. 5.

$$(I/\rho)\,(d^2x/dt^2) = F\rho - (mga \cos\theta) \qquad (5)$$

Elimination of $F$ from Eqs. 1 and 5 allows the acceleration to be written as

$$(d^2x/dt^2) = \mathrm{K}[\sin\theta - (a/\rho)\cos\theta] \qquad (6)$$

where

$$\mathrm{K} = (mg)/[m + (I/\rho^2)] \qquad (7)$$

Since $\theta$ and radius $r$ do not vary with time and, it is assumed, $a$ does not vary with time, Eq. 6 can be integrated to obtain the roll velocity as

$$v = dx/dt = \mathrm{K}[\sin\theta - (a/\rho)\cos\theta]\,t + v_0 \qquad (8)$$

where

$v_0$ = initial velocity of the roll down the ramp

Integrating once more yields the displacement

$$x = (\mathrm{K}/2)[\sin\theta - (a/\rho)\cos\theta]\,t^2 + v_0 t + x_0 \qquad (9)$$

where

$x_0$ = initial roll displacement

In the case where $\rho \cong r$, both models of rolling resistance presented in Fig. 6 yield exactly the same results.

#### Experimental results

In an effort to verify the correctness of the rolling resistance model, experiments were conducted in both field and laboratory settings. Field measurements were carried out in a linerboard paper mill and in a newsprint paper mill. In both cases, the paper rolls were considered to be hard rolls. Laboratory measurements were carried out with a butt roll of newsprint.

As illustrated in **Fig. 8**, the laboratory data cluster about the theoretical displacement curve with $a/\rho = 0.005$. The field data compare favorably with the curve for $a/\rho = 0$. The discrepancy between the data obtained in the field and the predicted values can be attributed to the difficulty in obtaining accurate rolling times.

This limited amount of experimental data cannot conclusively verify the theoretical approach. However, it does indicate that maximum values of roll velocity and displacement can be predicted with confidence. We expect to carry out additional experiments using a variety of rolls in the near future. Results of these experiments will be announced as soon as they are available.

## Safety considerations of ramp design

This discussion cannot identify all hazards or safety items associated with ramps. However, the following topics are of primary concern because they are encountered frequently.

#### Guard rails/steps

Ramps and access platforms are usually elevated from the floor. Consequently, consideration must be given to protect workers from falling. The Occupational Safety and Health Administration (OSHA) defines the design requirements for protection of open-side floors, platforms, runways, walkways, and work areas (*4, 5*).

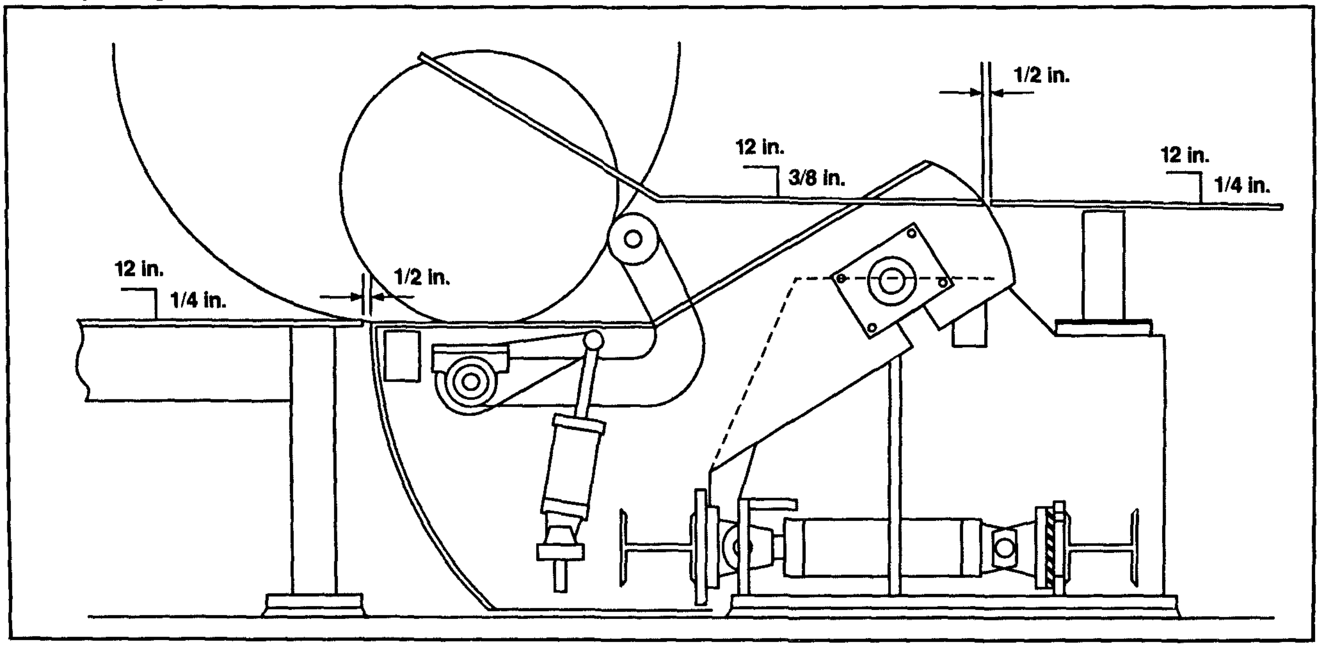
Generally, standard guard rails are required for open-sided platforms located four or more feet above the floor. Open-sided platforms located next to dangerous equipment or hazards must be guarded with standard railing and toe boards, regardless of elevation. Every flight of stairs with four or more risers must be equipped with standard stair railings or handrails.

Most of the ramps in a roll-handling system do not require the presence of workers except for maintenance. However, most roll wrappers are installed on platforms four to five feet above the shop floor. These installations typically include one or more operator work stations, and careful design must be exercised to protect workers while allowing sufficient access to materials and supplies (heads, end bands, labels, etc.).

#### "Ankle turners" and "balance breakers"

Another area of safety concern is the transition from the edge of a ramp to the adjacent floor. Concrete ramps should be constructed so that there are no sharp drop-offs where an operator could fall or injure an ankle. The transition should be made gradual by sloping the sides of the ramp down to the adjacent floor. Ideally, the slope of the transition should be 10% or less.

**9.** Safety skirting on an arm elevator




**Equipment skirting**

Devices mounted within ramps—rotating elements or components that periodically rise above and then return flush to the ramp surface—create potential pinch points that are especially dangerous to the feet of operating personnel. Any gaps created by the movement of the machinery must be skirted with metal plating. A typical device of this nature is an arm elevator. This device, which is commonly used to elevate or lower a roll from one elevation to another within a ramp, would present a significant hazard for operating personnel if it were not skirted to enclose all open sides and eliminate any gaps between its moving parts and the surface of the ramp. OSHA standards govern the design of this type of equipment, and manufacturers make great attempts to adhere to the requirements. **Figure 9** illustrates how such a device is skirted and demonstrates the concept.

**Lights and switches and paint**

All automated roll-handling systems use electrical controls such as photocells and limit switches. Generally, limit switches are operated by pivoting metal plates that are spring-loaded so that they protrude above the ramp surface. The switch is activated when a roll passes over the plate, setting up the control operations for the roll when it reaches the next station. Photocells are typically used to sense roll position. This information is used to control metering or to initiate an action within the roll-handling system.

The placement of these devices is extremely important from a safety standpoint, both to the equipment and to the operating personnel. The sensors should be located in guarded positions to avoid damage from adjacent operations, such as lift trucks. Their location also should be conspicuous to prevent operators from inadvertently activating an automatic operation that might pose a hazard.

Standard safety paint markings should be applied in accordance with OSHA color schemes to identify all moving parts and to identify control devices that initiate action.

## Conclusion and recommendations

Proper design of ramps for safe, controlled roll handling begins with a consideration of the physics of roll movement. The analytical procedure presented here can predict roll velocities and displacements along ramps. While not intended to eliminate the use of empirical design or testing, the procedure should prove to be cost effective by minimizing empirical effort. The analytical method also should prove to be useful in analyzing problems in existing systems where design modifications may be needed.

Further development of this analytical design tool should be done to

- Determine the correlation between roll hardness and rolling resistance
- Provide practical guidelines for ramp design
- Validate the analytical procedure for a broad range of paper grades.□

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