

**THE NATURE OF ADA'S SIDEWALK CROSS-SLOPES REQUIREMENTS:
A REVIEW OF THE LITERATURE**

by

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ABSTRACT

It is the long-term intent of the ADA that publicly available services along a public street be accessible to people with disabilities via a continuous unobstructed pedestrian circulation network. Almost all streets, with the exception of rural roads and highways, will (when altered) need to provide an accessible sidewalk wherever feasible.

This work describes existing research and science related to sidewalk cross-slope requirements in detail. It also summarizes the history and spirit of the Americans with Disabilities Act (ADA), discusses relevant court decisions, and identifies key ADA cross-slope-related requirements (and identifies any applicable caveats). Current practices rely on a combination of strict – but limited – physical solutions and some programmatic solutions that contain much uncertainty as to how and when they should be applied. Very little existing work considers the effort and other access differences that result from changes in cross slope. Thus, additional research is needed to ensure sound policy regarding user access to transportation facilities.

KEYWORDS

sidewalk accessibility, sidewalk cross-slope, disabilities, ADA

INTRODUCTION

The Americans with Disabilities Act (ADA) of 1990 embodies civil rights legislation that extends to individuals with disabilities comprehensive protections similar to those provided to persons on the basis of race, sex, national origin, and religion under the Civil Rights Act of 1964. The key requirement of the ADA relative to pathway cross slope is that a 36-inch width must be provided at no more than a two-percent cross slope¹ in order to be considered part of a pedestrian circulation network for people with disabilities. This includes sidewalks, curb ramps, driveway crossings, street crossings, locations where two sidewalks meet, *etc.*

It is the intent of the ADA that, in the long-term, all addresses that provide services to the public (*e.g.*, businesses, places of employment, government agencies) along a public street should be made accessible to people with disabilities via a continuous unobstructed pedestrian circulation network (*i.e.*, continuous passage). Therefore, almost all streets, with the exception of rural roads and highways, will (when altered) need to provide an accessible sidewalk wherever feasible. A major question is how direct must the path be from any point A to any point B in the network. In the law (for alterations), these paths must be direct to the “maximum extent feasible.”

The ADA consists of five titles. Title II’s provisions are fundamental to this review; they prohibit discrimination by state and local governments in the supply of services, including employment. Title III is also relevant to our discussion in that it prohibits discrimination by public accommodations and includes regulations and specifications for accessible construction and design that also apply to Title II.

Court rulings based on ADA indicate that there is a high standard for “undue burden” exemptions from ADA (*e.g.*, *Kinney v. Yerusalim* [CA 3 1993], cert. Denied, *Hoskins v. Kinney*, No. 93-1439 [US SupCt 4/18/94]; *Helen L. v. DiDario* [CA3 1995]; and *L.C. v. Olmstead*, No. 1:95-CV-1210-MHS [DC NGa 3/26/97]). However, a “good faith effort” by public agencies has been used successfully as a defense (*e.g.*, *Miller v. City of Johnson City, Tenn.* [DC ETenn 1996]). And it may be that conducting research to determine maximum bounds on cross slopes for various situations and users could be considered a “good faith effort.”

THE ADA ACCESSIBILITY GUIDELINES

The ADA Accessibility Guidelines (ADAAG) (see Access Board 1994 and DOJ 1998) are a set of standards for accessible design developed by the Architectural and Transportation Barriers Compliance Board (Access Board). These guidelines, covering new construction and alterations, acquire force of law when adopted into regulations established by the Department of Justice. Currently, the Department of Justice (DOJ) has adopted ADAAG Sections 1 through 10, concerning public accommodations and commercial facilities, into the Title III regulations.

Sections 11 through 14 of the ADAAG apply to Title II entities. They were developed to cover such programs and services as accessible public housing and public right-of-ways. On the basis of comments to proposed rulemaking, Sections 11 and 12 were incorporated into the ADAAG as final guidelines, but have not yet been adopted into the regulations by the Department of Justice. Section 13 is held in reserve while further guidelines are developed.

Section 14 is being held in reserve by the Access Board in favor of a campaign to focus on education and outreach regarding pedestrian facility design. (Access Board 1994) All the guidelines will be reissued for public comment under notices of proposed rule-making before final rules are issued. Until then, Title II entities have the option of using ADAAG, the Uniform Federal Accessibility Standards (UFAS), or DOJ-certified equivalent standards as guidelines for new construction and alterations. The complete ADAAG are expected to be ready for public comment by July 2000; Table 1 provides a timeline of relevant dates in the legislation's history.

Table 1. Legislative History of ADA Relevant to Sidewalks in the Public Right-of-Way*

July 26, 1990	The Americans with Disabilities Act (ADA) signed into law.
July 26, 1991	ADA Accessibility Guidelines (ADAAG) for new construction and alterations in places of public accommodation and commercial facilities published by the Access Board.
January 26, 1992	Titles II and III of the ADA become effective.
September 6, 1991	ADAAG amended to include requirements for transportation facilities (section 10).
December 21, 1992	Notice of Proposed Rulemaking (NPRM) to add ADAAG sections applicable to State and local government facilities, including section 14. Public Rights-of-Way.
June 20, 1994	Access Board publishes interim rule adding sections 11 through 14 to ADAAG.
January 13, 1998	Final rules for State and local governments published except for section 14, which was held in reserve due to concerns by the transportation community.
April 13, 1998	ADAAG for State and local governments become effective as advisory guidelines until adopted as standards by the Department of Justice and the Department of Transportation.
August 12, 1999	Access Board publishes notice of intent to establish a Public Rights-of-Way Access Advisory Committee to make recommendations for new guidelines.
October 20, 1999	Access Board publishes notice of appointment of Advisory Committee and first meeting date (November 29-30, 1999).
July, 2000	ADAAG are expected to be ready for public comment.

* Adapted from the Federal Register.

The ADAAG were primarily derived from the Uniform Federal Accessibility Standards (UFAS), which was published in 1984. The intent of the UFAS was to present uniform standards in accordance with the Architectural Barriers Act. Congress established the Architectural and Transportation Barriers Compliance Board (ATBCB), which is now the Access Board, to ensure compliance with the standards by issuing minimum guidelines and requirements.

Title II entities may use either the Uniform Federal Accessibility Standards (UFAS) or ADAAG, until a final version of the ADAAG is issued and adopted into the regulations. Since the ADAAG will eventually become the single federal standard, it seems prudent to use the ADAAG exclusively. There are no significant differences between the UFAS and ADAAG that would make one preferable over the other, except that the ADAAG allow for structural

impracticability in new construction while the UFAS do not, and the UFAS allow for a cost factor in making alterations accessible while the ADAAG do not. Table 2 provides a summary of the distinctions which do exist.

Table 2. Comparison of Relevant Requirements in ADAAG and UFAS*

Requirement being compared:	ADAAG	UFAS
Equivalent facilitation	Departures from particular standards are permitted where alternatives will provide substantially equivalent or greater access (§2.2).	UFAS itself does not contain a statement concerning equivalent facilitation. However, section 504 regulations, as well as the Department's title II regulation (28 CFR 35.151(c)), state that departures are permitted where it is "clearly evident that equivalent access" is provided.
Exemption from application of standards in new construction	Contains a structural impracticability exception for new construction: full compliance with the new construction standards is not required in the rare case where the terrain prevents compliance (§4.1.1(5)(a)).	Does not contain a structural impracticability exception (or any other exception) for new construction.
Exemption from application of standards in alterations	For alterations, application of standards is not required where it would be "technically infeasible" (i.e., where application of the standards would involve removal of a load-bearing structural member or where existing physical or site restraints prevent compliance). Cost is not a factor (§4.1.6(1)(j)).	Application of standards is not required for alterations where "structurally impracticable," i.e., where removal of a load-bearing structural member is involved or where the result would be an increased cost of 50 percent or more of the value of the element involved (§§4.1.6(3); 3.5 ("structural impracticability")). Cost is a factor. (Note that the similar term, "structural impracticability," is used in ADAAG, but in ADAAG it is used in relation to new construction. In UFAS, it is used in relation to alterations, and it has a different meaning.)
Detectable warnings	Required on curb ramps, hazardous vehicular areas, and reflecting pools. The warnings must be truncated domes (§4.29). (This requirement is suspended until July 26, 2001 (63 FR 64836)).	No requirements for detectable warnings.

*Table adapted from the DOJ Title II Technical Assistance Manual (USDOG 1992).

State and local agencies – such as state departments of transportation – fall under ADA’s Title II regulations. Sidewalks are regarded as pedestrian facilities covered under Title II, Part A, and are addressed in some detail in the proposed Section 14 of the ADAAG pertaining to public right-of-ways. In general, all facilities designed, constructed, or altered on behalf of or for the use of a public entity must be readily accessible and usable by individuals with disabilities, if the construction or alterations begin after January 26, 1992 (28 CFR 35.151). This means that the facility must be designed, constructed, or altered in strict compliance with a design standard that

is certified by the DOJ as ADA equivalent, such as the existing UFAS (as long as it is applicable), or the ADAAG.

In addition to and apart from construction standards, Title II entities subject to Part A fall under the “program accessibility” requirement, which states: “A public entity may not deny the benefits of its programs, activities, and services to individuals with disabilities because its facilities are inaccessible.” A public entity’s services, programs, or activities, when viewed in their entirety, must be readily accessible to and usable by individuals with disabilities (28 CFR 35.149 - 35.150).

An important limitation of the program’s accessibility requirement is that a public entity does not have to take any action that it can demonstrate would result in either (1) a fundamental alteration in the nature of its program or activity, or (2) an “undue burden,” meaning undue financial or administrative burdens. If an action would result in such an alteration or such burdens, the public entity must take any other action that would not result in such burdens, but would nevertheless ensure that individuals with disabilities receive the benefits and services of the program or activity. In the case of sidewalks, the benefit is that pedestrians have access to places that provide employment or services to the public. People with disabilities must also have access to these services and benefits. If the same sidewalk used by other pedestrians does not provide this access, then it must be provided by some other means.

As previously stated, Sections 1 through 10 of the ADAAG were adopted into the Title III regulations by the DOJ and carry the force of law. These guidelines contain specifications for pedestrian routes in general, including such sidewalk elements as running slope, landings, cross slope, width, overhead obstructions, and curb ramps. Specifications for curb ramps must also be considered in driveway crossings and are addressed in Section 4.7. The final ADAAG will contain guidelines for Title II entities that are consistent with guidelines for Title III entities, unless there is a compelling reason for them to be different; therefore, Title II entities should observe requirements in the Title III regulations, where applicable.

The proposed Section 14 of the ADAAG, concerning public right-of-ways, gives more detailed specifications and guidelines on continuous passage, sidewalks, and other accessible elements of the right-of-way (ROW). Based on feedback from various stakeholders, the Access Board decided to reserve these guidelines in favor of working with other governmental and private sector organizations in the transportation industry to promote the incorporation of pedestrian accessibility criteria into industry guidelines, standards, and recommended practices (63 FR 2000, January 13, 1998).

The proposed Section 14 of the ADAAG recognizes that modifications and specific requirements respond to the unique nature and function of public right-of-ways (ROWS). For example, natural terrain, constrained width, the number and complexity of services that must be accommodated within and along the ROW, and the demands of adjacent development may offer little opportunity for the creation of accessible routes as required by Title III guidelines. Section 14 is based on the concept of a *continuous passage* to connect public sidewalks, curb ramps, and street crossings into a pedestrian network that serves both adjacent sites and elements intended for pedestrian use on and along the public sidewalk (36 CFR Part 1191). *Continuous passage* is

analogous to the *program accessibility* requirement for Title II entities. The service in question is pedestrian access in the public ROW; continuous passage constitutes accessibility to this program or service.

In Section 14, continuous passage is defined as "...a continuous unobstructed pedestrian circulation path within a public sidewalk connecting pedestrian areas, elements, and facilities in the public right-of-way to accessible routes on adjacent sites. A continuous passage is provided in lieu of an accessible route in a public right-of-way." An *accessible route* is an unobstructed path connecting all accessible elements of a building or facility. Although public sidewalks are subject to technical provisions similar to those that apply to accessible routes, public sidewalks are not required to meet guidelines for accessible routes unless the public sidewalk is used to provide the required accessible route connecting accessible elements on a site.

The ADA does not require construction of sidewalks where none previously existed, unless other work of a significant enough nature is being done to the adjacent street (*e.g.*, reconstruction). The Access Board has indicated that the ADAAG do not require construction of new public sidewalks. However, under the program accessibility requirement of Title II, construction of a pedestrian walkway where none existed previously may be necessary to ensure that individuals with disabilities have access to a particular state or local program, such as a school (USDOJ, 1996).

The ADA and the associated ADAAG make it clear that accessible sidewalks require limited cross sloping. Government agents wish to be in compliance but may find that variable terrain conditions, restricted right-of-ways (ROWs), city codes, and existing infrastructure may inhibit their efforts to provide a cross slope of less than or equal to the required two percent at all points along an accessible route. For example, there may be difficulties when a sidewalk crosses one or more steeply graded driveways in hilly terrain. Many public agencies have voiced their concerns regarding the cross-slope standards. In a personal communication in January 1999, Lois Thibault of the Architectural and Transportation Barriers Compliance Board (Access Board) stated that cross slope was one of the most controversial portions of the Draft ADAAG Section 14 on Public Right-of-Ways.

With respect to the precise origin of the two-percent sidewalk cross-slope requirement, anecdotal comments from several ADA "experts" were inconsistent. Some said it was based on scientific research, others said it was not. One remembered something about a HUD study, another thought that a Veterans Administration study had some say in it. One said that it probably arose from a combination of prior guidelines, such as architectural building guidelines and roadway/sidewalk drainage guidelines. Another said it was most likely a negotiated settlement, as are many of the individual requirements of the ADA, with perhaps some original basis in science and prior guidelines. The latter opinion seems to be the most likely, as it incorporates all the other comments into one plausible theory. No matter how it got there, one question still remains: Is there any research and science to back it up? This answer to this question is focus of this review.

Our review of the existing literature on this topic of persons with disabilities and cross-slope suggests that there is no substantive, non-anecdotal evidence on which the two-percent

requirement might be based. It is possible that two percent was a negotiated settlement and may not need to be strictly observed to achieve the intent of the ADA. The latter is more probable if the requirement is relaxed only in isolated instances, such as driveway crossings with limiting terrain conditions, with the backing of scientific evidence. In any case, it is desirable to impose requirements on the public and its agents that are based on substantive argument and evidence. Presently, research is underway at the University of Texas at Austin to provide such evidence for cross-slope regulations.

TARGET STAKEHOLDERS

In drafting the Americans with Disabilities Act (ADA) in the late 1980s, Congress found that a significant proportion of Americans (an estimated 20 percent) have one or more physical or mental disabilities, and that this percentage increases as the population ages. Obviously, many persons with disabilities have concerns related to sidewalk cross slope. These concerns contributed to the ADA cross slope requirement in the first place. To discuss these, it is important to consider people with different types of disabilities, including those who have auditory, visual, and/or ambulatory impairments.

In the review of the literature on the topic of cross-slopes, no documentation was found for auditory and visually impaired pedestrians. However, it would seem that increased cross slope might increase the possibility that the visually impaired would be led off the sidewalk (in the direction of the cross slope) if a proper texture/color border is not provided to distinguish the sidewalk boundary and provide lateral orientation.

In a draft document, the Access Board (1998) states that “excessive cross slope is the single greatest barrier to travel along sidewalks and shared-use paths for pedestrians who use wheelchairs and scooters, pedestrians who use walkers and crutches, pedestrians who have braces or lower-limb prostheses, and those with gait, balance, and stamina impairments.” This statement seems a little strong. It seems that *primary slope* may be a much greater barrier to those with stamina impairments, that primary slope or pavement smoothness would be a greater barrier to manual wheelchair users, and that insufficient sidewalk width would represent a greater barrier to crutch users.

Sidewalk cross slopes can impact those with ambulatory impairments. Kathy Johnson (Access Board, 1997) states that (1) the chance for lower crutch slippage is increased and (2) turning is more difficult on non-level surfaces, the latter being of most importance at intersections with other sidewalks or walkways used to access buildings (possibly including driveways). Also, crutch users appear to be especially susceptible to cross slope when travelling downgrade (Access Board, 1998).

It is important to note that any wheelchair/crutch slippage or loss of balance will typically project the pedestrian towards the street, and it is reported that children with disabilities may be less able than adults to compensate for cross slope (Access Board, 1998). Also, driveway aprons constructed like ramps, with steep short side flares, may cause wheelchair, walker, and crutch users to tip or fall (Access Board, 1998).

In a survey of almost 600 wheelchair users, Kirby *et al.* (1994) report that 57.4 percent had completely tipped or fallen from their wheelchairs at least once. Of these, 24.2 percent were in the sideways direction. Results also indicated that 16 percent of such accidents were serious (*i.e.*, resulting in fractures) and many of these accidents occurred outdoors or on ramps. Clearly, excessive slope can present a dangerous condition.

Although no detailed discussions were found in the literature, many other factors in conjunction with cross slope may impact the perception of comfort and level of service (for people with disabilities) when traveling on a sidewalk. These other factors include:

- (1) length of continuous sidewalk route sections exceeding two-percent cross slope,
- (2) proportion of entire sidewalk route exceeding two-percent cross slope,
- (3) adjacent automobile traffic volume and the separation distance from such traffic,
- (4) sidewalk pavement condition (type, texture, state of repair, iced over or wet, *etc.*),
- (5) primary sidewalk slope (note: downgrade and upgrade effects differ) (Axelson, 1998),
- (6) weather,
- (7) sidewalk width, and
- (8) degree of accessibility of the entire route (including curb cuts, street crossings, *etc.*).

Several sidewalk route elements are of concern relative to cross slope, including driveway crossings, street crossings, and curb ramps. However, driveway crossings seem to be the primary sidewalk section where the two-percent ADA cross-slope requirement is difficult to meet. Public agents must trade off the cost and feasibility of meeting this requirement in conjunction with meeting the needs of people with disabilities. Since driveway crossings are relatively short, it seems possible that people with disabilities could negotiate greater cross slopes over some driveway crossings that are difficult to construct below two percent. The constraining or “design disability” factor would seem to be the effort required (or comfort) of manual wheelchair users when traversing a cross-sloped section. However, it is also possible that slippage (either crutch or wheelchair) could be the constraining factor in some situations. The design disability might differ for different routes if the latent/unobserved demand for the facility can be estimated in terms of people with different disabilities, or if the section is often wet or icy. The following section, which discusses the biodynamics literature on this subject, aids this understanding.

RESEARCH AND SCIENCE

Existing scientific research on perception of effort by people with disabilities when traversing cross-sloped surfaces is quite limited. Much of what is available can be found in the medical rehabilitation research literature. Such studies usually are designed to explore the control and design of wheelchairs, not the perceptions of users while traveling on sidewalks. Therefore, these studies are only partially applicable to the issue of cross-slope. In fact, very few articles deal directly with the effects of cross slope; most focus on the directional stability of wheelchairs. With the exception of recent research performed by Kockelman *et al.* (1999), no studies could be found pertaining to the effects of cross slope on people who use other walking aids, such as crutches and walkers.

In a film about sidewalk accessibility, Dennis Cannon (Access Board, 1997) states that 50 percent more effort is required for a wheelchair user to traverse a 3-percent cross slope relative to a two-percent cross slope. Cannon goes on to point out that there is increased difficulty in traversing a cross slope in combination with a primary grade, such as that on a ramp, when using a wheelchair. He also points out that slipping is more apt to occur the greater the cross slope, especially under wet or icy conditions. Finally, he illustrates some of the differences in motorized and manual wheelchairs, though not specifically in the context of cross slope.

Based on a review of the scientific literature related to cross-slope design, one is forced to conclude that prior research is insufficient to support the ADA's two-percent cross-slope requirement. Studies show, as expected, that the propulsion (in terms of force), the net energy cost, and the work per meter on a two-percent cross slope is greater than that required for a level surface. However, Chesney and Axelson's work (1996) suggests that the difference in wheelchair-user effort between traversing cross slopes in the range of 2 percent to 5 percent may not be very large (about 20 percent), and that this effort may only double when increased from two percent to about 16 percent. Only one, very recent study has attempted to find the cross slope at which wheelchair-user effort becomes "too high" when traversing a cross-sloped section (Kockelman *et al.*, 1999). Essentially all studies have weaknesses that prevent one from drawing strong inferences relative to the design of sidewalk cross slopes for people with disabilities. These weaknesses include small sample sizes, lack of diversity in the samples, lack of realism in experimental design relative to traversing actual sidewalks, and lack of consideration of other factors that might impact perception (*e.g.*, length of traversed section and adjacent traffic volume).

Kockelman *et al.*'s research team administered surveys to volunteers with disabilities through on-site and Internet-based surveys and then used an ordered response model of user perception of sidewalk-section crossing difficulty and a weighted linear regression model of heart rate deviations from resting rate. Their model estimates permit estimation of reasonable cross-slope maxima for sidewalk users with various disabilities. For example, using the perception-of-sidewalk-accessibility data and making some assumptions about where to draw the line in terms of probability of persons being able to cross a section, the resulting critical cross-slopes for 5.0% and 0% main grades were estimated to be 12.1% and 5.3%, respectively. These thresholds are significantly higher than the blanket ADAAG cross-slope standard of two-percent. While Kockelman *et al.*'s sample size and variety is an order of magnitude more extensive than those of prior studies considering cross-slope, there were only 19 respondents to their field survey and most of these were in their 40's and only three respondents relied on crutches or canes. Of the 6.4 million persons using assistive devices "for getting around," national data indicate that 79% use crutches or canes and 73% are age 55 or older (NCHS 1993); so these groups represent a sizable part of the population with disabilities and may need to be better sampled.

A second relevant study is that provided by Chesney and Axelson (1996), who focused on developing a method to objectively measure the effort of wheelchair users on a variety of surfaces. An important point made in their conclusions is that the work required to negotiate a specific ramp angle may be viable as a pass/fail criterion for short-distance wheelchair travel. This might include the short distance required to traverse a driveway. Chesney and Axelson

(1996) also acknowledge the need to assess the impact over much longer distances, such as for single trips and for all trips during the day. Broadly interpreting their ideas, one could consider developing a *performance measure* for sidewalk accessibility by first dividing a route into various sections, with the boundaries defined by cross-slope and main-grade changes. Multiplying the length of distinct sidewalk sections by their respective work-per-meter value, summing over all sections on a route, and then normalizing to a work-per-mile value could be a very effective accessibility performance measure. Such a measure explicitly considers driveway crossings that have cross slopes in excess of two percent. The measure could be compared to a threshold or “break point” criterion obtained by survey and experimentation on a sample of wheelchair users selected to reflect the general population and used in conjunction with short-distance bounds for individual driveway crossings.

Also of note is Chesney and Axelson’s use of the SMART^{wheel} to measure pushrim forces. This equipment can be useful as a supplement to oxygen-uptake and heart-rate monitors in measuring effort. Measurements were taken on an adjustable plywood ramp set at different grades, cross slopes, and grade/cross-slope combinations. A primary weakness of the study, with respect to cross-slope design, is that only one 166 lb test subject and one wheelchair were used. Additionally, the test surface was plywood, not sidewalk paving material. Rolling resistances are typically 1.5 times greater on concrete relative to treadmills (Brubaker, 1986), and treadmill surfaces probably more closely approximate plywood than concrete. In addition, the studies were conducted exclusively in laboratory settings, leaving experimentation in actual sidewalk environments unexamined. Thus, there is a significant and clear need to go beyond the lab environment — to actual sidewalks and pathways — in order to obtain a realistic measure of actual effort on typical TxDOT and local pedestrian facilities, as Kockelman *et al.* (1999) have done.

One interesting result of the Chesney and Axelson (1996) study is that the work-per-meter value on a two-percent primary grade does not change for marginally different cross slopes, as shown in Table 3. This is in clear contrast to Cannon’s remark that a 3 percent cross-slope requires 50% more effort than a two percent (Access Board, 1997), and this supports the possibility that a cross-slope range wider than 0 to two percent might be acceptable by wheelchair users when traversing short distances. However, the researchers make no explicit attempt to assess a user “break point” or threshold for distances similar to driveway crossing widths, except to suggest using the work-per-meter for some (undetermined) primary ramp slope as the “break point.”

Table 3. Average Work-per-Meter Required to Propel a Wheelchair across a Plywood Ramp (Chesney and Axelson, 1996)

Grade	Cross Slope	Average Work per Meter (Newton-meters)	Standard Deviation (Newton-meters)
2%	0%	26.32	1.39
8%	0%	71.48	1.43
2%	2%	31.54	0.48
2%	3%	33.81	0.41
2%	5%	37.91	0.50
2%	8%	45.25	0.77
2%	12%	55.46	0.95
2%	14%	58.76	0.61
2%	16%	62.23	1.88
2%	20%	75.04	3.08

At a primary ramp slope of 8 percent (the ADA maximum is 8.33 percent), the “break point” would be at about 70 Newton-meters. This suggests a maximum *cross-slope* bound in the neighborhood of 16 to 20 percent. However, ramp slopes are of a shorter duration than driveway crossings, so this “break point” would probably be lower. In addition, their research does not address whether this bound is suitable for the general population of interest. Nor does it assess differences in user perceptions of sidewalk cross slope, especially variances in perception across the population and across sidewalk environments. Finally, the study does not investigate a 0-percent grade with different cross slopes.

In a related area of work, Brubaker *et al.* (1986) attempt to identify and quantify several factors affecting directional stability of manual wheelchairs on uneven and two-degree (3.5-percent) cross-sloped surfaces. Their work considers the drag and propulsion for a standard and a sport wheelchair using one athletic young male paraplegic on a motorized treadmill, not on sidewalk paving material. They measure the subject’s oxygen consumption, heart rate, and stroke rate. Their findings indicate that the compensation for the downhill turning moment of a wheelchair on a two-degree (3.5 percent) cross slope results in a retarding force approximately equal to the rolling drag of a wheelchair on a level surface. However, they estimate that the net *energy* cost (oxygen consumption) of propulsion on a two-degree (3.5-percent) cross slope to be only 30 percent greater than that for a level surface. This is in general agreement with Chesney and Axelson’s (1996) results, which indicate a 28 percent work increase between 0- and 3-percent cross slopes (on a primary grade of two percent). In another paper, Brubaker (1986) concludes that “minimization of downhill turning tendency is most effectively and practically

achieved by moving the center of mass toward the main wheel axis.”Brubaker *et al.* (1986) find that the mechanical efficiency (defined as the ratio of power required to energy cost) of propulsion on the slope is higher than that on the level surface. They attribute this to the “more favorable conditions with respect to the force-velocity relationship of the muscles” and also to the fact that only one arm is used for propulsion, meaning only one arm is active in the recovery phase that uses energy, but does not produce any work. However, as expected, the “efficiency of travel” on the slope is lower, based on the ratio of net oxygen consumption to distance traveled.Unfortunately, the work by Brubaker *et al.* (1986) does not explore cross slopes greater than two degrees (3.5 percent) or investigate how a variety of users would perceive this increased effort in actual sidewalk travel environments. Therefore, one cannot draw from their results very strong inferences regarding the design of sidewalk-driveway crossings.

Cooper (1989) investigates the directional stability of racing wheelchairs on crown roads and concludes that crown compensation mechanisms appear to solve most of the directional instability problems induced by roadway crowns. He derives the equations necessary to specify the minimum spring force required to compensate for the downhill turning moment and compares these to the actual preset forces for various compensators. The force required for maintaining directional stability is found to be less than that needed to deflect the crown compensator. This study relies on an extremely small (nondiverse) sample (three athletes), which Cooper notes is a common problem in rehabilitation research. The wheelchairs used are of a racing design that is probably not common in sidewalk travel. Most importantly, the study does not address the range of cross slopes that ordinary wheelchair users might find acceptable for short distances at sidewalk-driveway crossings, unless one wants to make some (strong) assumptions regarding possible future wheelchair technology improvements.

There has been a great deal of work studying the static and dynamic stability of wheelchairs on various ramp grades. These studies support an upper bound on wheelchair-accessible primary ramp slope of 5 to almost 13 percent, and the static stability of wheelchairs seems to be maintained in situations with larger than 10-percent forward and backward slope. Also supported is the fact that sideways static stability of wheelchairs can be achieved on at least a 5-degree (8.7-percent) cross slope. There is also some research on the demand for transportation of people with ambulatory impairments.

Researchers at Syracuse University have studied maximum primary ramp slopes and the relationship between slope and length using a plywood ramp surface in a laboratory environment (HUD 1979). In this work they measure heart rate to assess overexertion. If an excessive amount of time is needed, or if after a two-minute rest following the trial the user’s heart rate has not returned to within 10 beats of the resting rate, the ramp negotiation is termed “unsuccessful.” Almost half the wheelchair users did not successfully negotiate a 40-foot ramp sloped at 8.33 percent. About one-third did not complete even 5 feet. Of those unable to manage the 8.33 percent slope, 67 percent were able to travel at least 30 feet on a 6.25 percent slope. All wheelchair users completed the full 40-foot length of a ramp sloped at 5 percent.

Sanford *et al.* (1996) studied 171 subjects of all ages using different types of mobility aids as they traversed a 30-foot ramp whose slope varied from 5 percent to 12.5 percent. Pulse rate,

energy expenditure, speed, distance traveled, and resting locations were recorded. Of all the subjects, only a few manual wheelchair users had difficulty traversing the 30-foot ascent.

Canale *et al.* (1991) tested the criteria for ramp construction for wheelchair users using a sample of 140 individuals having different levels of impairment. They concluded 15 percent to be the maximum allowable slope for a 1-meter ramp and 10 percent to be the maximum for a 3-meter ramp.

Kirby *et al.* (1992) tested the static and dynamic forward stability of occupied wheelchairs by using a down ramp and a 5-cm obstruction. No cross-slope stability tests were considered. Gaal *et al.* (1996) conducted a similar test and neglected any cross-slope effects. Kirby *et al.* (1996) examined the rear stability of occupied wheelchairs, using a positively tilted platform. No consideration of cross slope was made.

Guerette *et al.* (1995) pointed out that current standards for ramp slope and length generally have been established based on performance of young, strong, male wheelchair users, and that evidence suggests that current standards may not be appropriate for a wide range of older users and users having severe functional limitations.

Finally, there are other, less applicable studies that arise in the literature; these include the following:

- (1) Cappozzo *et al.* (1991) sought a reliable prediction of length and grade limits for ramps that can be traversed by any special category of wheelchair-dependent individuals by measuring the maximal voluntary force.
- (2) Lawrence *et al.* (1996) considered wheelchair ride comfort via subjective response by wheelchair users.
- (3) O'Connor *et al.* (1996) studied three-dimensional kinematic variables of racing wheelchair propulsion to improve the efficiency of racing wheelchairs.
- (4) Brubaker *et al.* (1984) estimate wheelchair propulsion efficiency for various combinations of speed and technology. They found that wheelchair-use efficiency was higher over 1-degree (1.7-percent) and two-degree (3.5-percent) slopes than over a level section.
- (5) Woude *et al.* (1988) studied how changes in grade and speed impact mechanical efficiency and effort. They found that a low-speed/high-slope combination is more efficient than the reverse (for the same energy input). They used several cardio-respiratory measures, including gross mechanical efficiency, ventilation, oxygen consumption, and heart rate.

CONCLUSIONS AND SUMMARY

The ADA represents powerful legislation that attempts to prevent discrimination and prejudice from denying people with disabilities the opportunity to pursue equal opportunity, full participation, independent living, and economic self-sufficiency. Accessibility to opportunities and services through sidewalk design is a part of this legislation, and present accessibility guidelines for cross-slope suggest that two percent should be the maximum built. Through the course of this research, the exact history of this two-percent sidewalk cross-slope requirement

could not be ascertained, and no research and science supporting a unilateral two-percent requirement was found.

Results from the most relevant existing reported work, conducted using plywood ramps, can be interpreted to indicate a maximum “short-distance” cross-slope upper bound in the neighborhood of 16 to 20 percent (Chesney and Axelson, 1996). For somewhat longer distances, a reliable upper bound may be closer to 10% (Kockelman *et al.*, 1999). These results support the idea that the ADA’s two-percent limit might be too strict for relatively infrequent short-distance sidewalk sections, such as driveway crossings, when considered in combination with the various constraints. Further research is required to accommodate larger samples of users with disabilities and more robustly determine such bounds and to identify under what conditions they would apply (*e.g.*, the maximum length of an individual section). In addition, a route performance measure may be very useful, in conjunction with a short-distance bound.

Primarily owing to ROW constraints and existing driveway grades, it does not appear that the *design*-related methods found in the literature will adequately address concerns for meeting the intent of ADA at difficult sections (*e.g.*, when connecting to existing infrastructure, such as steep driveways in hilly areas). Programmatic methods, such as relying on ADA caveats, outreach to the community of people with disabilities, and the “do the best you can” approach may pose too much risk to be adequate in and among themselves. Public agencies can be (and have been) challenged in court for “do the best you can” solutions and interpretations of the ADA caveats.

In summary, public provision of transportation facilities for use by people with disabilities offers challenges in terms of access and costs. Current practices rely on a combination of limited physical solutions for strictly meeting ADAAG and programmatic solutions that contain much uncertainty as to how and when they should be applied. Very little existing work allows one to appreciate the effort and other access differences that result from changes in cross slope. While recent cross-slope research by Kockelman *et al.* (1999) and Chesney and Axelson (1996) is relevant to national and international efforts to ensure access to all users of transportation facilities, additional investigations – with greater sample sizes – is still needed and will enable sounder policy.

ENDNOTE

¹ The two-percent sidewalk cross-slope requirement is intended to be an in-place, finished-product construction standard, rather than simply a design standard (which is subject to deviations owing to actual construction practices) (Access Board, 1998).

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