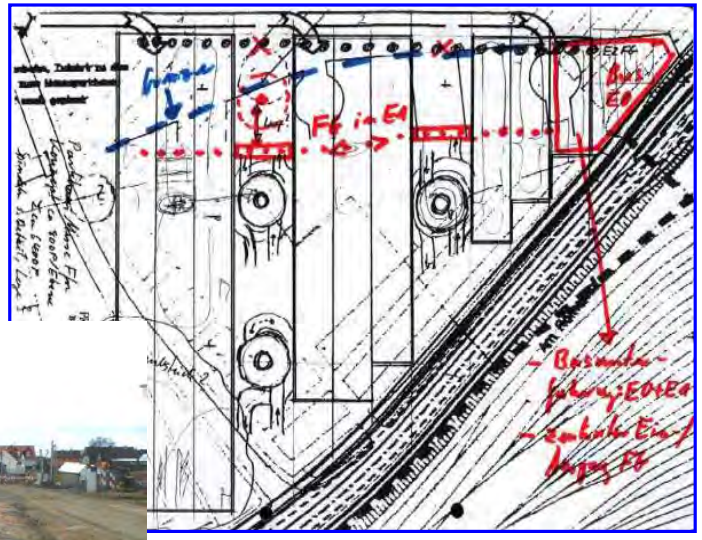
- **Content**

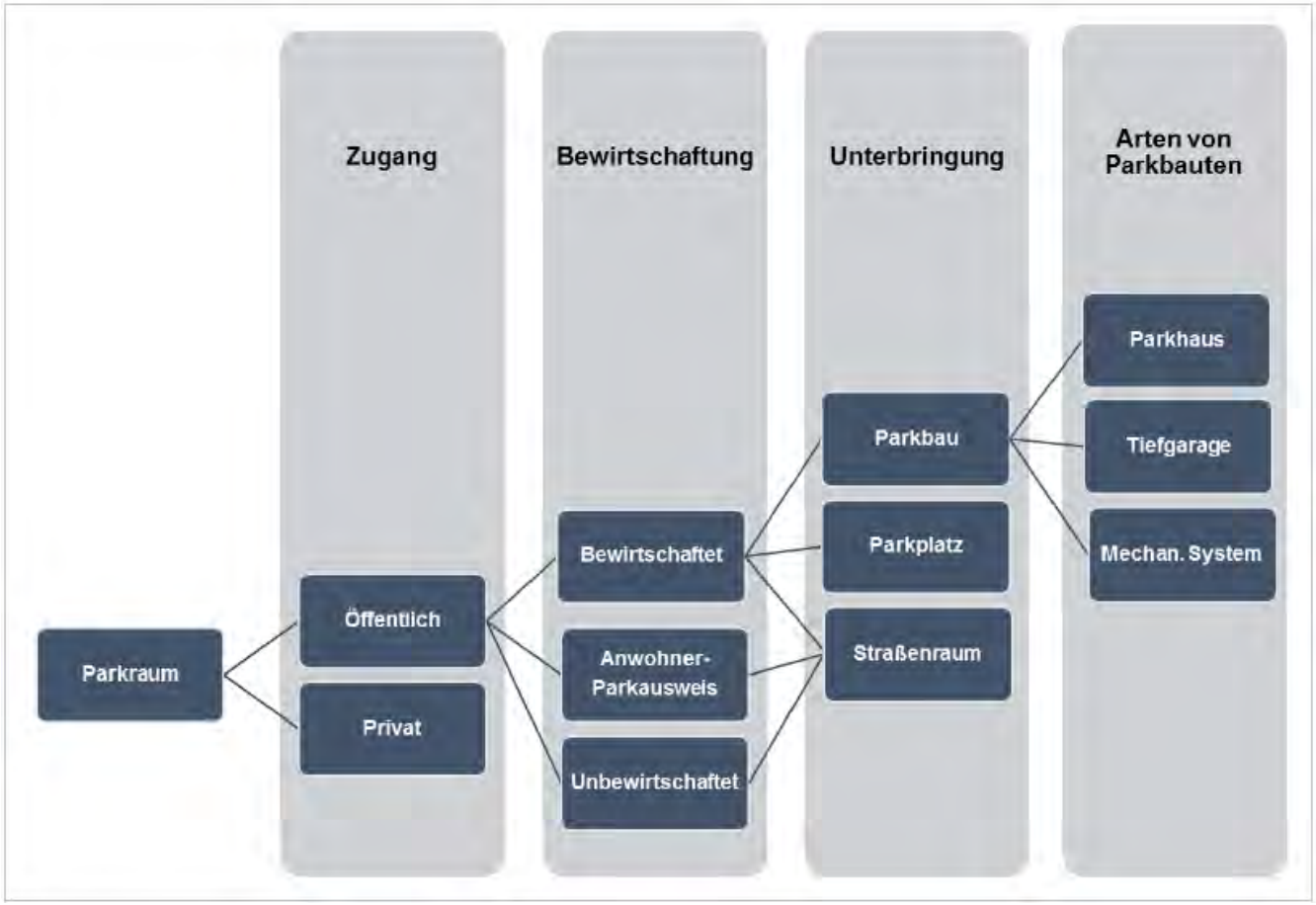
1. **Introduction (general aspects, parking policy, trip generation)**
2. **Design vehicle**
3. **Parking lots and lanes**
4. **Headroom**
5. **Ramps**
6. **Queue length**
7. **Construction aspects of parking facilities**
8. **Bicycle parking**
9. **Loading dock and truck parking**

Sources: Numbered references see last page, other sources are mentioned when occurring. No responsibility for external links.

- **Content**
  1. Introduction
  2. Design vehicle
  3. Parking lots and lanes
  4. Headroom
  5. Ramps
  6. Queue length
  7. Construction aspects
  8. Bicycle parking
  9. Loading docks



Introduction: Differentiation of parking facilities



Source 15; p. 11

Introduction: Costs and m² for parking facilities:

Kind of parking	Cost of building € / parking spot	Cost of operation € / parking spot / month
Parking lot	1.000 – 3.000	20 – 25
Parking garage	5.000 – 15.000	25 – 35
Underground Parking	15.000 – 40.000 and more!	30 – 40
Full mechanical system	15.000 – 30.000	25 – 45

Source 8; p. 24

ready for operation, but without cost for the site

staff on 6 days a week

Art des Parkraums	Durchschn. Flächenverbrauch
Parken am Straßenrand	8 - 12 m²
Ebenerdige Parkplätze	20 m²
Parkbauten	25 – 30 m²

Source 15; p. 14

Introduction (parking demand):

- High demand for parking in the city
- Demand for amount of parking lots can be determined by analysing:
  - Reason to park (e.g. shopping, work, residential)
  - Time of parking (length and by whom at that time)
  - Wrong parked vehicles (lack of parking spots)
  - Distance (e.g. to an office or mall)
- Different motives to park lead to different needs in parking

- **Introduction (parking demand): Characteristics and sensibilities of demanding groups:**

		Residents	Employees, Students	Customers	Visitors and Guests	Service provider	Delivery sevice
Time length of parking	short	OO	OO	XX	XO	XO	XX
	long	XX	XX	OO	XO	XO	OO
Depends on public parking spots		XO	XO	XO	XO	XO	XX
Usage of other transportation possible		OO	XX	XO	XO	OO	OO
Long walking distance reasonable		OO	XX	XO	XO	OO	OO
Parking fees purposeful		OO	XO	XX	XX	XX	OO
Responds to guidance system		OO	OO	XO	XX	XO	OO

XX = applies XO = partly applies OO = does not apply

Source 1

Introduction (parking demand):

- **Parking need:**
  - » **Car is parked ca. 23h a day**
  - » **Desire of comfort: Distance vehicle – destination ca. 300m; if not possible → illegal parking**
  - » **Different demand and parking periods depending on the time of day have to be considered**

- **Introduction (parking demand):**
  - **Lack of parking spots in a city lead to obstacle for traffic → well planned parking concept needed**
  - **Examples for concepts of parking:**
    - **Keep as many cars out of city center as possible (e.g. pt provisions, p+r facilities, ped + bike improvement)**
    - **Parking fee regulation (the closer to the center, the more expensive)**
    - **Parking on street side in small citys**

    →Concept depends on the city

- **Introduction (parking demand):**
  - **Different types of parking lots:**
    - » **Parking spots without charge in the street or in lots**
    - » **Chargeable parking spots in the street or in lots**
    - » **Residential parking in the street**
    - » **Parking spots in parking and underground garages**
    - » **Private parking spots in parking lots**
  - **Amount of parking spots needed is regulated locally**

    →Every city handles number of parking spots to be established for a new building differently

Introduction (parking policy):

- Even with very good public transportation system many parking spots are needed e.g. Frankfurt Main: ~ 12.000 public spots in 22 garages (city center)
- Guidance system needed
- Amount of parking spots to be built depends on usage of the building and quality of service of public transport

Introduction (parking policy, example Frankfurt):

- Frankfurt regulates the number of parking lots depending on the quality of public transportation
- Disabled parking lots and apartment parking lots have to be built regularly
- Office parking lots are reduced by 30 to 85 %, depending on the area
- Restriction areas are defined by distance to the city center respectively the kind and frequency of public transportation

Introduction (parking policy, example Frankfurt 2017):

Anlage 1 - Stellplatzzahlen

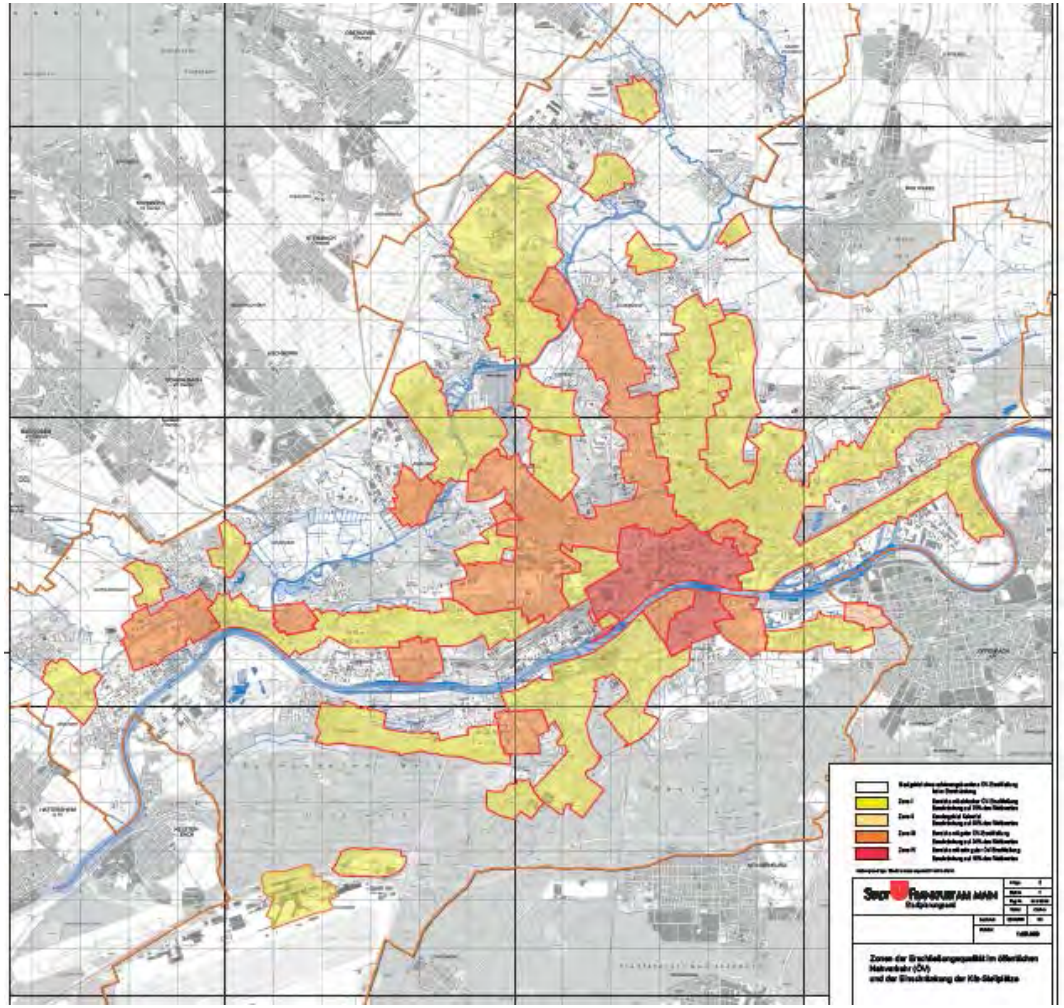
	Verkehrsquelle	Zahl der Stellplätze für Kraftfahrzeuge	Zahl der Abstellplätze für Fahrräder
1	**Wohnungen**		
1.1	Ein- und Zweifamilienhäuser	1,5 je Wohneinheit (WE)	3 je WE
1.2	Mehrfamilienhäuser (ab 3 WE)	Außerhalb der Zonen I bis IV: 1,1 je 100 qm BGF Zone I : 1,0 je 100 qm BGF Zone II : 0,8 je 100 qm BGF Zone III : 0,8 je 100 qm BGF Zone IV : kein Stellplatzbedarf	1 je 40 qm BGF
1.3	Kinder- und Jugendwohnheime	1 je 20 Betten, mindestens 2	1 je 2 Betten
1.4	Wohnheime	1 je 3 Betten, mindestens 2	1 je 2 Betten
1.5	Altenwohnheime	1 je 10 Betten, mindestens 2	1 je 10 Betten
2	**Büro- und Verwaltungsräume, Räume für freie Berufe**		
2.1	Büro-, Verwaltungsräume, Praxen freier Berufe	1 je 50 qm BGF	1 je 125 qm BGF mindestens 3 je Einheit

… and more

Introduction (parking policy, example Frankfurt):

Restriction zones

		Stadtgebiet ohne schienengebundene ÖV-Erschließung keine Beschränkung
	Zone I	Bereiche mit einfacher ÖV-Erschließung Beschränkung auf 70% des Richtwertes
	Zone II	Sondergebiet Kaiserlei Beschränkung auf 50% des Richtwertes
	Zone III	Bereiche mit guter ÖV-Erschließung Beschränkung auf 30% des Richtwertes
	Zone IV	Bereiche mit sehr guter ÖV-Erschließung Beschränkung auf 15% des Richtwertes



Introduction (parking policy, example Frankfurt):

Example Frankfurt:

Mixed building outer city center (zone III)

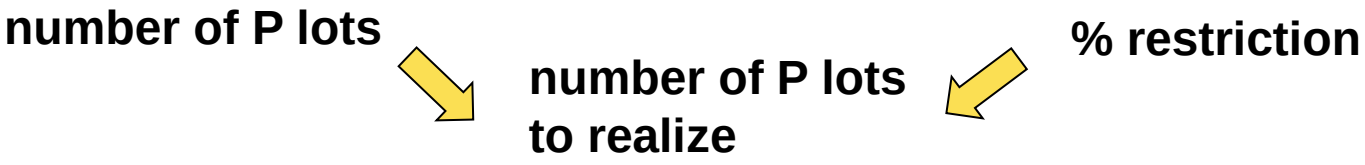
Office 30.000 m² gfa; appartments 5.000 m² gfa.

App.: 0,8 P / 100m² → 50*0,8 = 40 P, 100% allowed.

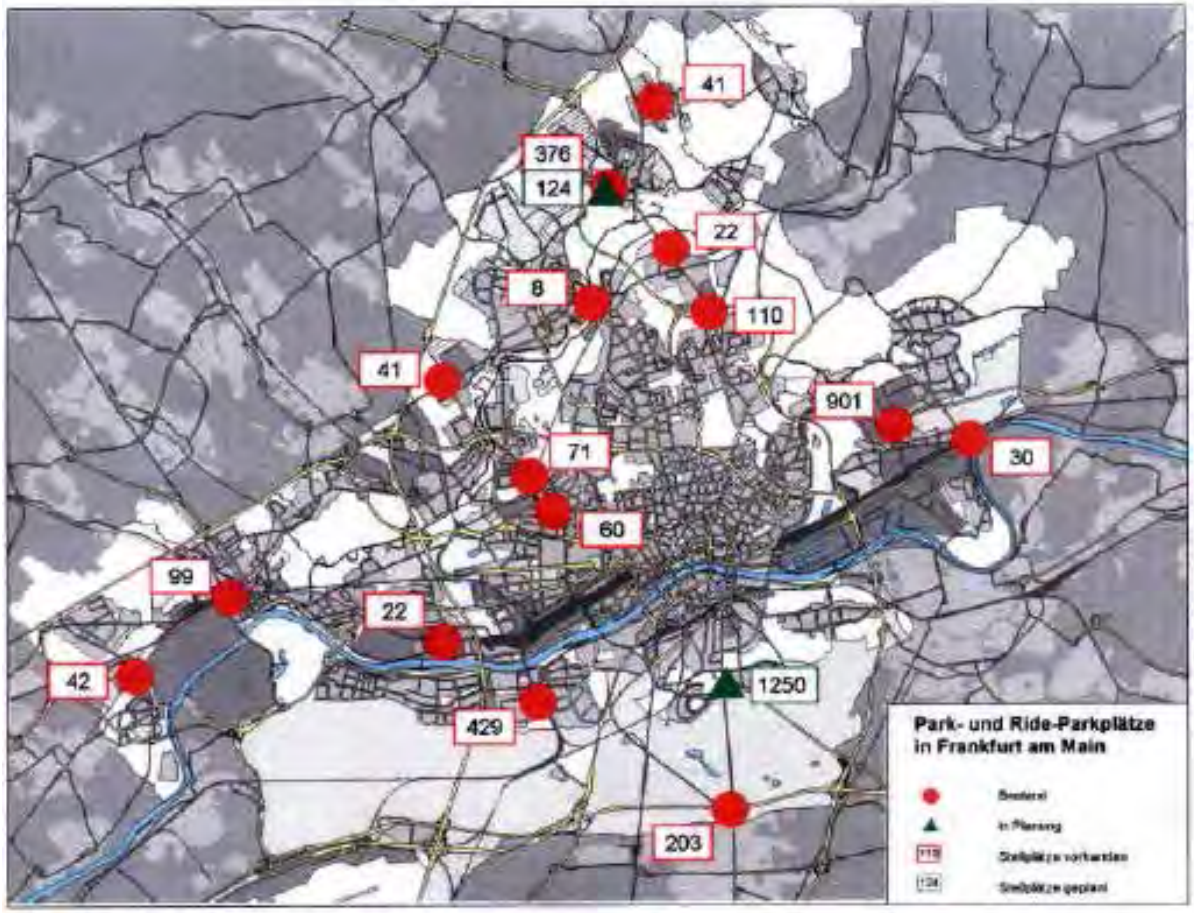
Office: 1 P / 50m² → 600 P with no restriction zone,

restriction zone III: 30% realization allowed = 180 P

→ Garage to be built: 40 + 180 = 220 P



Introduction, Park + Ride Frankfurt ~ 2000



Bestand:

15 Plätze
mit 2.404 Stellplätzen

In Planung:

1 Platz (neu)
mit 1.250 Stellplätzen

1 Platz (Erweiterung)
mit 124 Stellpätzen

Introduction (regulations Zagreb):

Na **1.000 m²** građevinske (bruto) površine, ovisno o vrsti i namjeni prostora u građevinama, mora se osigurati broj parkirališno-garažnih mjesta prema sljedećoj tablici:

NAMJENA PROSTORA U GRAĐEVINI	PROSJEČNA VRIJEDNOST	LOKALNI UVJETI
Stanovanje	11	8-14
Proizvodnja, skladišta i sl.	6	4-8
Trgovine	30	20-40
Drugi poslovni sadržaji	15	10-20
Restorani i kavane	45	30-60
Fakulteti i znanstvene ustanove	10	5-15

GFA → number of P lots to realize (more details in the text)

PROČIŠĆENI TEKST ODLUKE O DONOŠENJU
PROSTORNOG PLANA GRADA ZAGREBA
Službeni glasnik br. 8/01, 16/02, 11/03, 2/06, 1/09 i 8/2009
Zagreb, 24.03. 2009.

5.1.3. Parkirališna i garažna mjesta

Introduction (parking policy, residential parking WI):

Zählbereiche 1.5 bis 1.9 Elsässer Platz Umgebung mit Parkscheibenregelung und Anwohnerparkzone (im Bereich ca. 150m Entfernung)

Stellplatzerhebung Bereich 1: Elsässer Platz WI, Prof. Dr. Ing. Rudolf Eger, April 05

Anzahl Stellplätze in den erfassten Bereichen: Σca. 230 Stpl.

1.5, Nettelbeckstr.

1.6, Nettelbeckstr.

1.7, Gneisenaustr./ Goebenstr.

1.8, Blumenthalstr./ Steinmetzstr.

1.9, Elsässer Str.

Schilder der Parkzone mit Regelung Parkscheibe 2h, Mo-Fr 09-20 Uhr, ansonsten frei für Bewohner

Signs for residential parking zone:

2h allowed, Mo-Fr 09-20 from 20-09 only for residents with permit.

Introduction (parking policy, residential parking WI):

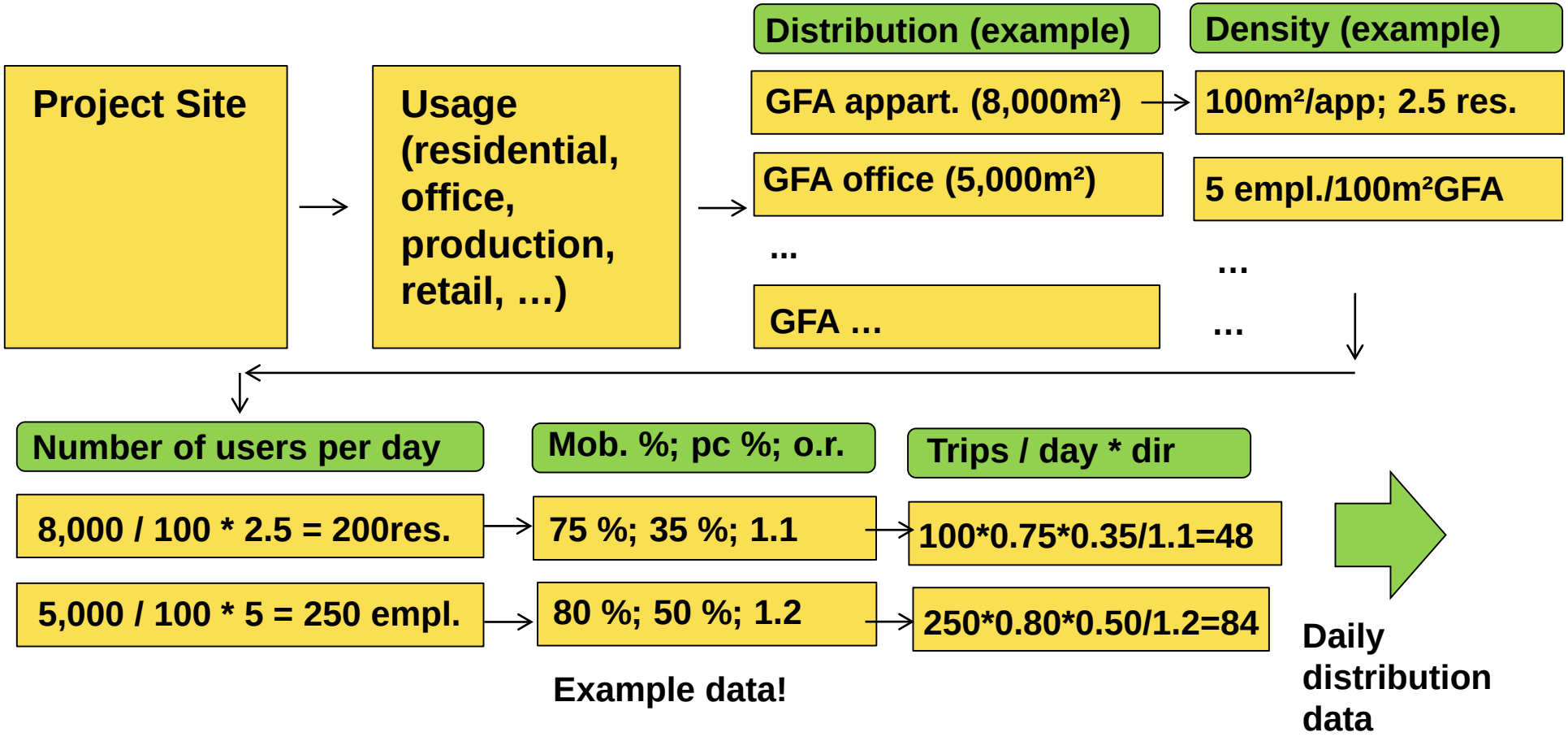
Bewohnerparkausweis | © wiesbaden.de

Fee (2014): 23,50 € for two years

Introduction (trip generation of parking facilities):

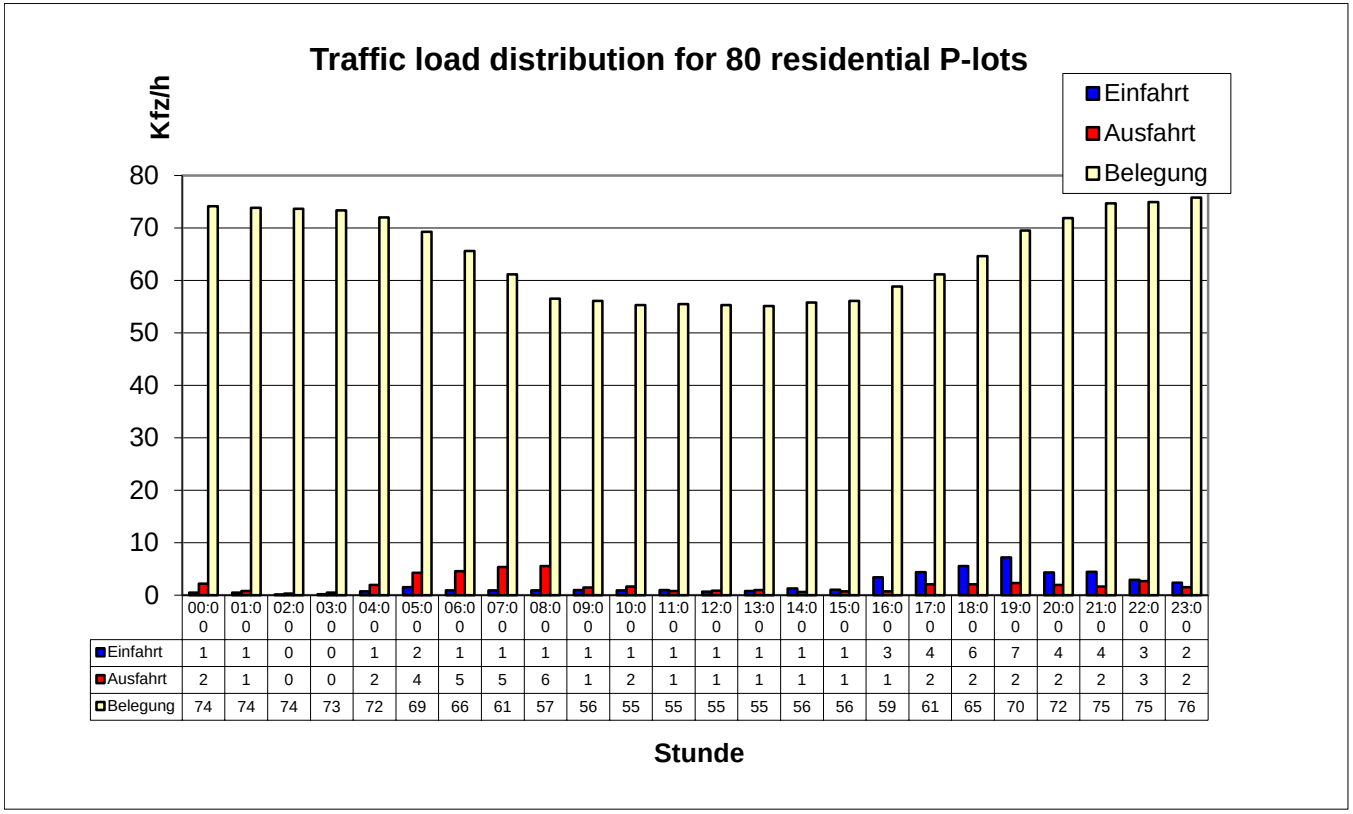
- Who will use the parking (user groups)?
- How many parking lots are needed?
- How many cars will enter/ exit the parking per day and per peak hour?
- Which facilities and how many are needed at entrance and exit (queue length not on public space!)?

Introduction (trip generation of parking facilities):



Introduction (trip generation of parking facilities):

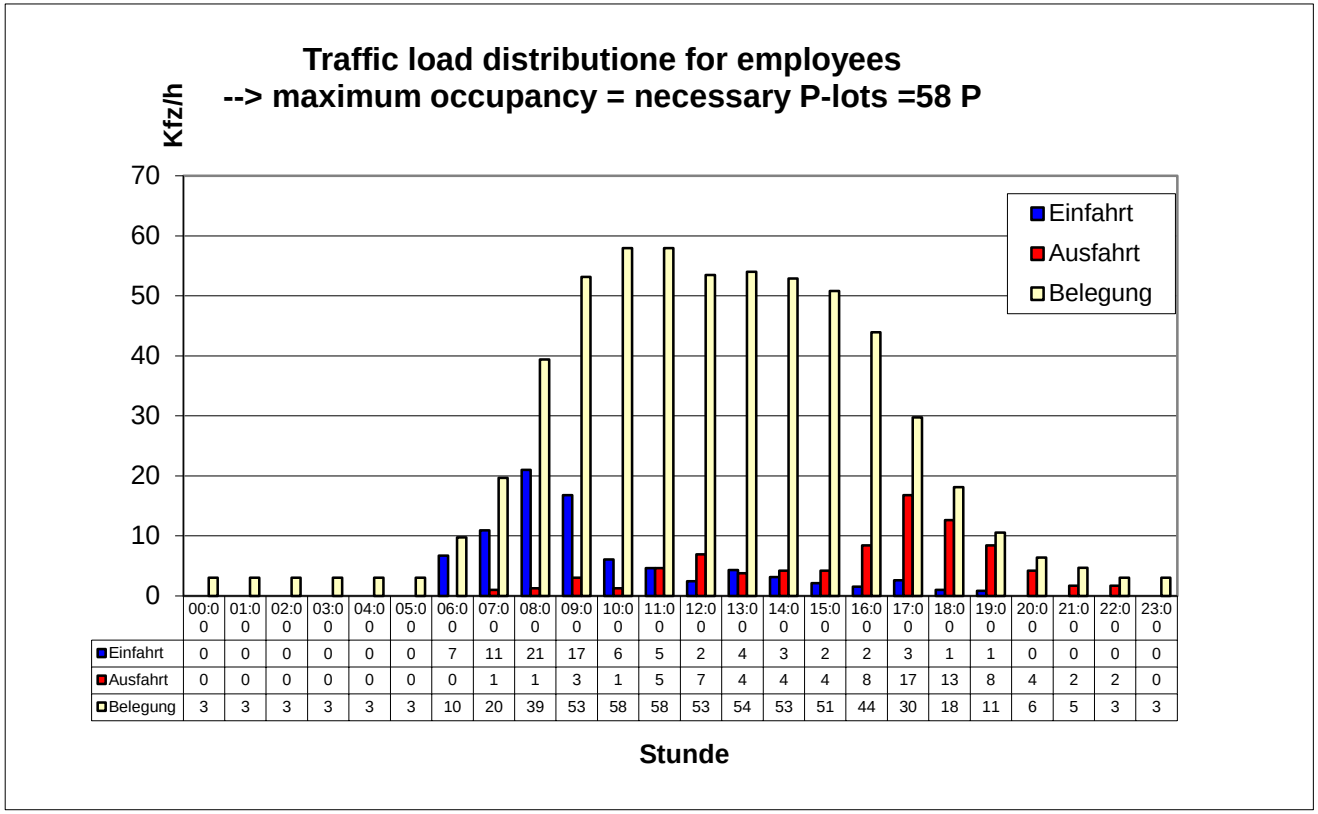
Example: 80 P for residential appartements. Assumption: 90 % of P (=72 P) occupied at 04:00 a.m.; city center, 48 trips/ day * direction



	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Einfahrt	1	1	0	0	1	2	1	1	1	1	1	1	1	1	1	1	3	4	6	7	4	4	3	2
Ausfahrt	2	1	0	0	2	4	5	5	6	1	2	1	1	1	1	1	1	2	2	2	2	2	3	2
Belegung	74	74	74	73	72	69	66	61	57	56	55	55	55	55	56	56	59	61	65	70	72	75	75	76

Introduction (trip generation of parking facilities):

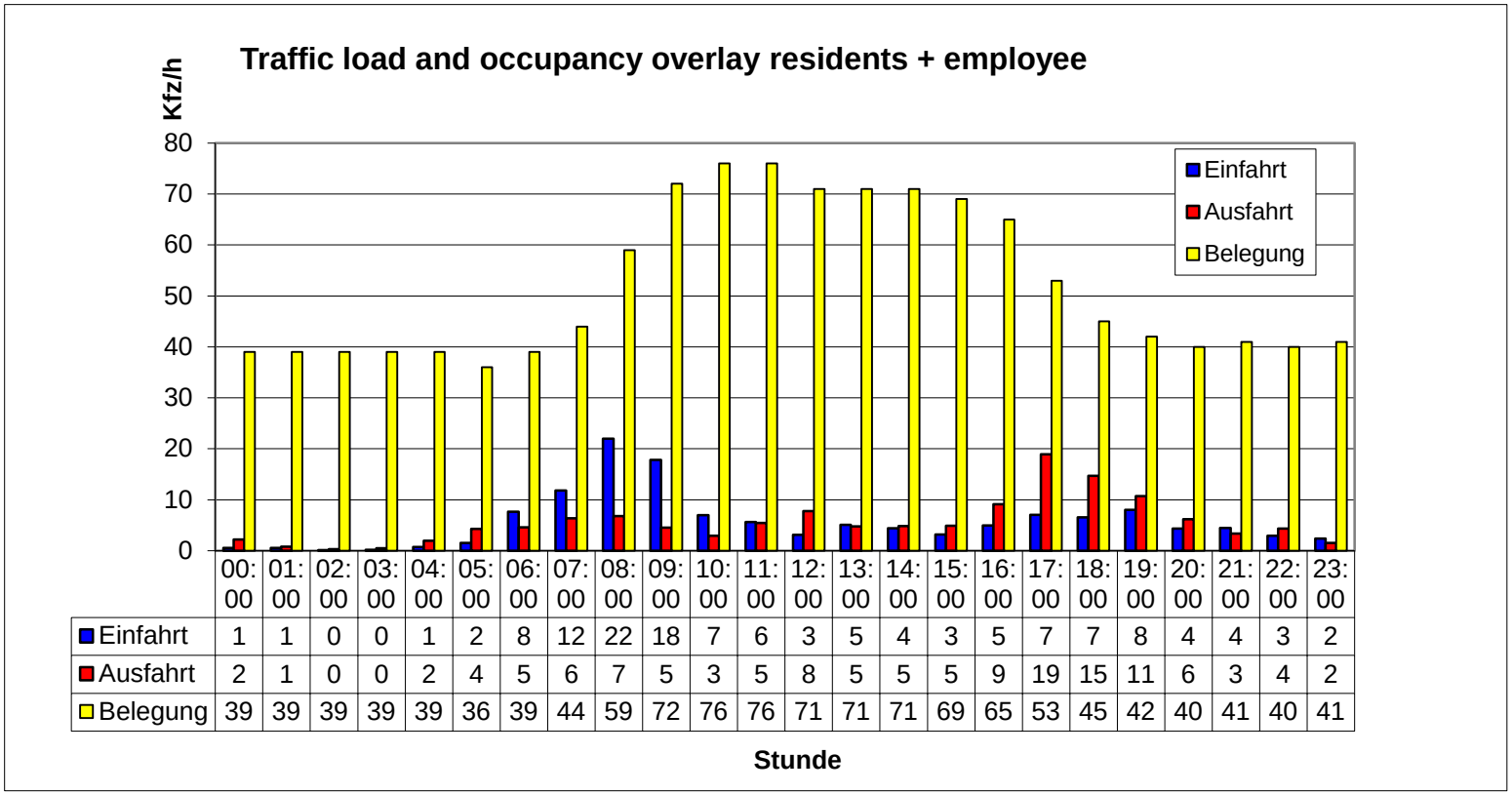
Number of P for employees → 60 P (example). Assumption: 5 % of P (= 3 P) occupied at 04:00 a.m.; 84 trips per day and direction; city center



	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Einfahrt	0	0	0	0	0	0	7	11	21	17	6	5	2	4	3	2	2	3	1	1	0	0	0	0
Ausfahrt	0	0	0	0	0	0	0	1	1	3	1	5	7	4	4	4	8	17	13	8	4	2	2	0
Belegung	3	3	3	3	3	3	10	20	39	53	58	58	53	54	53	51	44	30	18	11	6	5	3	3

Introduction (trip generation of parking facilities):

Overlay → 76 P (example) peak occupancy. 22 pc/h morning peak entering; 19 pc/h evening peak exiting (number of lots: 40 res + 60 empl = 100 P)

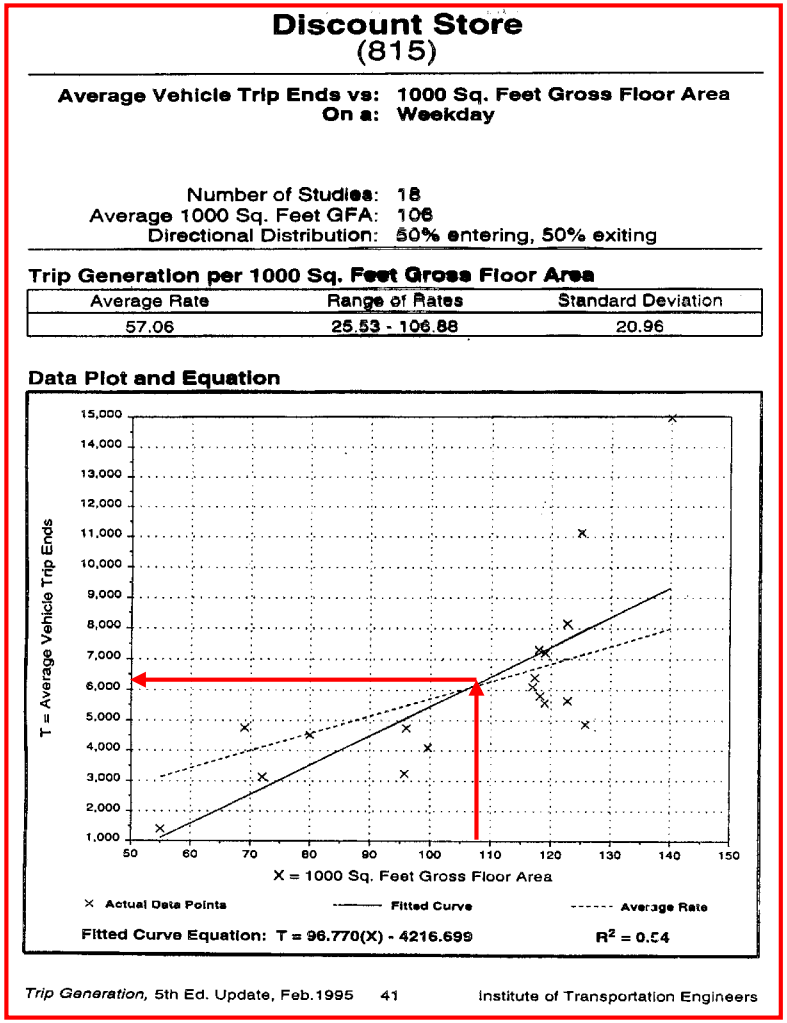


	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Einfahrt	1	1	0	0	1	2	8	12	22	18	7	6	3	5	4	3	5	7	7	8	4	4	3	2
Ausfahrt	2	1	0	0	2	4	5	6	7	5	3	5	8	5	5	5	9	19	15	11	6	3	4	2
Belegung	39	39	39	39	39	36	39	44	59	72	76	76	71	71	71	69	65	53	45	42	40	41	40	41

Introduction (trip generation of parking facilities):

Greatest difficulty: reliable data!
In USA: „Trip generation“
Institute of transportation engineers (ite.org)

Example: Discount store (outer city)
1 m² = 10,76 sqft; 1000 sqft = ~ 93 m²
Average: 106,000 sqft = ~ 9,860 m²
Average Rate: 57 [trip/1,000sqft*d] =
57/0,93 = ~ 61 [pc/100m² GFA*d]
50% enter/ exit = ~ 30 [pc/100m² GFA*d*dir]
10,000 m² GFA = ~108,000sqft
→ ~ 6,200 [pc/d] = ~ 3,100 [pc/d*dir]
Thumb rule store: 1 P lot changes 3.5 per day
→ ~ 3,100 / 3.5 = ~ 890 P-lots needed
(more acurate calculation with traffic load distribution data!)



Discount Store
(815)

Average Vehicle Trip Ends vs: 1000 Sq. Feet Gross Floor Area
On a: Weekday

Number of Studies: 18
Average 1000 Sq. Feet GFA: 106
Directional Distribution: 50% entering, 50% exiting

Trip Generation per 1000 Sq. Feet Gross Floor Area

Average Rate	Range of Rates	Standard Deviation
57.06	25.53 - 106.88	20.96

Data Plot and Equation

Trip Generation, 5th Ed. Update, Feb.1995 41 Institute of Transportation Engineers

Tagesganglinien für den Kfz-Verkehr für Fahrtzwecke ohne den Zweck Freizeit:
Prozentuale Verteilung des Tagesverkehrsaufkommens auf die einzelnen Stunden-Intervalle

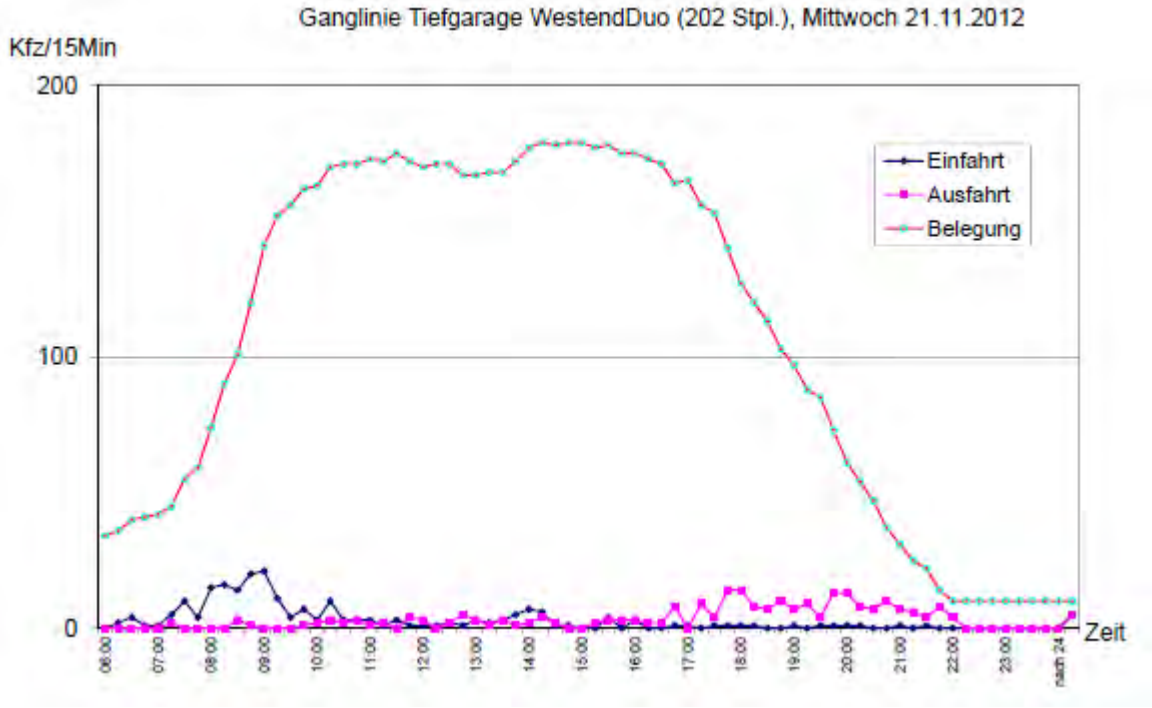
Stunden-Intervall	Fahrtzweck												Stunden-Intervall
	Einwohner-Verkehr*)		Berufs-Verkehr*)		Ausbildungs-Verkehr*)		Kunden- und Besucherverkehr Einzelhandel kleinflächig mittwochs		Einzelhandel großflächig donnerstags		Wirtschafts-Verkehr*)		
	Montag-Freitag		Montag-Freitag		Montag-Freitag						Montag-Freitag		
	Quell-V.	Ziel-V.	Quell-V.	Ziel-V.	Quell-V.	Ziel-V.	Quell-V.	Ziel-V.	Quell-V.	Ziel-V.	Quell-V.	Ziel-V.	
	%	%	%	%	%	%	%	%	%	%	%	%	
00–01	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	00–01
01–02	0,00	0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	01–02
02–03	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	02–03
03–04	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	03–04
04–05	1,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	04–05
05–06	1,50	0,25	1,00	6,75	0,00	2,75	0,00	0,00	0,00	0,00	1,00	1,50	05–06
06–07	15,00	0,90	2,00	22,20	0,00	4,50	0,00	0,00	0,00	0,00	1,75	3,00	06–07
07–08	14,00	2,00	4,50	28,70	0,00	37,20	0,64	0,98	0,00	2,70	4,75	8,00	07–08
08–09	8,00	2,50	5,25	8,75	0,00	21,00	2,89	5,73	3,50	5,05	6,50	10,40	08–09
09–10	5,25	2,75	3,50	1,75	0,00	11,00	8,55	8,78	5,40	8,65	8,25	8,75	09–10
10–11	4,25	3,50	3,25	1,00	0,00	4,50	9,31	11,46	7,60	8,75	9,00	10,25	10–11
11–12	3,00	5,25	2,50	0,50	5,85	1,50	10,94	9,15	8,60	7,35	10,25	9,90	11–12
12–13	3,50	7,50	13,00	5,20	11,00	1,50	4,91	5,61	8,70	6,75	8,75	7,00	12–13
13–14	5,50	7,00	11,75	13,40	18,00	3,00	8,55	7,44	5,90	4,95	7,75	6,50	13–14
14–15	6,00	4,25	6,00	5,40	8,35	1,75	9,31	8,66	6,00	6,05	5,60	6,00	14–15
15–16	4,75	6,50	7,00	1,75	7,85	2,00	8,43	8,66	5,90	6,95	7,00	7,75	15–16
16–17	6,00	14,00	11,75	1,25	12,70	0,00	11,07	12,32	8,40	9,65	8,75	6,75	16–17
17–18	7,50	13,75	13,75	1,00	8,85	4,80	15,09	13,41	10,60	12,00	7,00	5,00	17–18
18–19	4,50	10,40	7,00	0,25	5,00	4,50	10,31	7,80	13,60	14,10	5,25	3,75	18–19
19–20	4,25	6,00	2,50	0,40	5,35	0,00	0,00	0,00	12,60	7,05	3,75	3,25	19–20
20–21	2,00	3,75	2,00	0,00	9,35	0,00	0,00	0,00	3,20	0,00	1,75	1,45	20–21
21–22	0,50	3,50	1,25	0,70	4,10	0,00	0,00	0,00	0,00	0,00	1,00	0,25	21–22
23–24	0,00	2,00	0,50	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,65	0,00	23–24
Summe	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	Summe

Introduction (trip gen. of P-fac.): Germany: Traffic load distribution as % of daily trips (enter = exit) for certain land use.
(source 11)

But: a certain single building can have a different distribution and higher or lower peaks!!

See example next page.

Introduction (trip generation of parking facilities):



<u>Empirical data</u>:
Parking garage (office building, high riser Frankfurt city center):
202 lots
220 pc/d enter
244 pc/d exit
peak hour enter (07:00-08:00):
71 pc/h = 35 % of total enter
(compare 29 % FGSV source 11)
peak hour exit (17:30-18:30):
43 pc/h = 18 % of total
(compare 14 % FGSV source 11)

Introduction (some regulations, there are a lot!):

EPA – Checklist for the European Standard Parking Award

1.	MANDATORY MINIMUM CONDITIONS: If all these conditions are not fully satisfied the car park cannot be considered for an award.			
		Value	Compliant	Comment
1.1	Car park must be for public use			
1.2	Minimum headroom = 1.90 m			

Verordnung über den Bau und Betrieb von Garagen und Stellplätzen
(Garagenverordnung - GaVO)
vom 16. November 1995, geändert durch Verordnung vom 3. Februar 2009 (GVBl. I S. 30)

Empfehlungen für die Anlagen des ruhenden Verkehrs

EAR 05

Ausgabe 2005

DK 625.746.533.85

Ukupno stranica 1

JUGOSLAVENSKI STANDARD S OBAVEZNOM PRIMJENOM od 1980-06-04	Oznake na kolniku UZDUŽNE OZNAKE Definicija i podjela	J U S U.S4.221 1980.
	Pravilnik br. 31–3529/2 od 1980-02-28; Službeni list SFRJ, br. 17/80	
	Road markings. Longitudinal markings. Definition and classification	

- **Content**
  1. Introduction
  2. Design vehicle
  3. Parking lots and lanes
  4. Headroom
  5. Ramps
  6. Queue length
  7. Construction of parking facilities
  8. Bicycle parking
  9. Loading docks

- **Design vehicle:**
  - **Determines the width of a road and the size of a parking spot needed to fit the vehicle**
  - **Design vehicle is defined for all kinds of vehicles (truck, bus, garbage truck, fire truck etc.)**
  - **Definition not only important for parking, but also for designing roads**

- **Design vehicle:**
  - **Design vehicle for parking lots should be a personal car, which represents 85% of the currently running cars in the region where the garage is situated; this means only 15% of the cars around can be bigger**
  - **Exact size of a design vehicle is not specified by any law, only guidelines are given out by different sources e.g. European Parking Association or EAR**

- **Design vehicle:**
  - **Cars are getting bigger, mainly the width (+8 cm) and the height (+16 cm) since 2000 in Germany**

Table 1. Development of design personal car size in Germany (85 % car)

Year	Length [m]	Width (without mirrors) [m]	Height [m]
1975 / 1991	4,70	1,75	1,50
2000 / 2005	4,74	1,76	1,51
2010 / 2011	4,77	1,84	1,67

→ Many parking lots are too small for the new cars

Source 2

- **Design vehicle:**
  - **Examples for change of car sizes:**

Source 2

- **Design vehicle:**
  - **Two ways to determine the length, height and width of the design vehicle:**
    - » **Considering the amount of car registrated**
    - » **Considering just the car types available**

Table 2.1: Size not considering occurrence

Segment	Kenndaten			
	Länge [m]	Radstand [m]	Höhe [m]	Breite ohne Spiegel [m]
Minis	3,72	2,38	1,56	1,68
Kleinwagen	4,08	2,53	1,55	1,73
Kompaktklasse	4,50	2,66	1,52	1,79
Mittelklasse	4,80	2,74	1,50	1,85
Obere Mittelklasse	4,96	2,77	1,48	1,87
Oberklasse	5,41	3,16	1,49	1,89
Geländewagen	4,86	2,90	1,85	1,93
Sportwagen	4,71	2,75	1,36	1,94
Mini-Vans	4,37	2,64	1,67	1,82
Großraum-Vans	4,83	2,86	1,76	1,89
Utilities	5,20	3,28	2,25	2,01
Alle	4,90	2,90	1,76	1,90

Table 2.2: Size considering occurrence

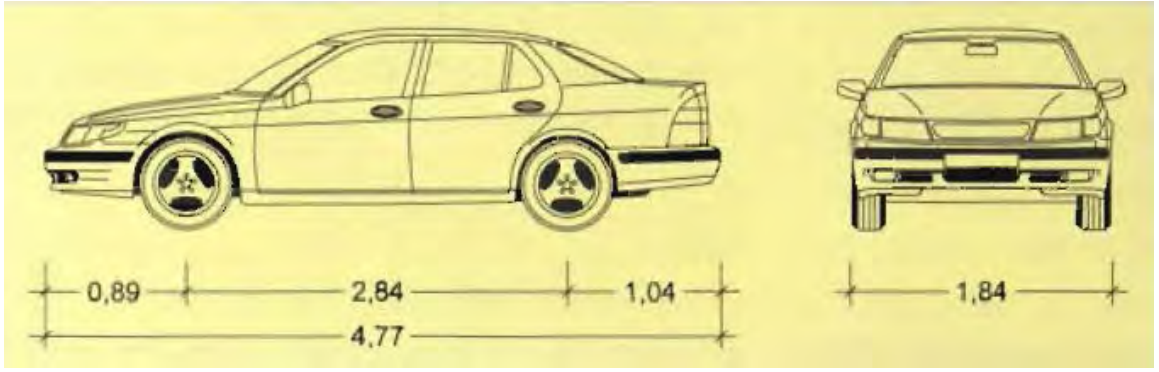
Segment	Kenndaten			
	Länge [m]	Radstand [m]	Höhe [m]	Breite ohne Spiegel [m]
Minis	3,64	2,38	1,56	1,65
Kleinwagen	4,07	2,51	1,53	1,73
Kompaktklasse	4,47	2,66	1,52	1,79
Mittelklasse	4,81	2,79	1,49	1,85
Obere Mittelklasse	4,93	2,95	1,51	1,87
Oberklasse	5,20	3,12	1,49	1,95
Geländewagen	4,77	2,85	1,75	1,91
Sportwagen	4,68	2,76	1,38	1,84
Mini-Vans	4,38	2,75	1,65	1,83
Großraum-Vans	4,78	2,85	1,73	1,88
Utilities	5,15	3,23	2,06	1,93
Alle	4,77	2,81	1,67	1,84

Source 3

- **Design vehicle:**

  For economically building of parking lots, the size of the design vehicle is determined weighing the amount of registered vehicles

  → Design vehicle in Germany 2011:



Source 4

~ Equal to: Mercedes C-Class

Source 5

Design vehicle Croatia 2011: 4.70m x 1.85m

The analysis was performed separately for each type and model of vehicle. The results are presented in *Table 2*.

Table 2 - Results of car dimension analysis

	Length/m	Width/m	Height/m
Average	4.194	1.736	1.506
Median	4.469	1.787	1.514
85-th percentile	4.572	1.820	1.620
90-th percentile	4.667	1.832	1.651
95-th percentile	4.765	1.857	1.725
Minimum	2.500	1.495	1.225
Maximum	5.255	2.374	2.415

classes, as well as in the overall average of passenger car dimensions.

From the performed analysis of registered vehicles in the Republic of Croatia and the selected 90-th percentile dimensions for the typical vehicle are; length 4.667m and width 1.832m.

Based on these calculations a conclusion is drawn that a vehicle with a length of 4.700m and width of 1.850m should be used as a typical vehicle for designing parking space dimensions in the Republic of Croatia

5. CALCULATION OF PARKING SPACE DIMENSIONS

Source 14

- **Design vehicle:**
  - **For special purposes other design cars representing 85 % of a certain class should be chosen, e.g. for garages**
    - » **where more luxury cars and/ or SUVs can be expected;**
    - » **or levels of garages designed for ultra small vehicles**

Table 2. Special car-classes in Germany (85 % car of the class 2010/11)

Car-class	Length [m]	Width (without mirrors) [m]	Height [m]
Ultra-small (e.g. Smart)	3,64	1,65	1,56
Upper	5,20	1,95	1,49
SUV (e.g. Porsche Cayenne)	4,77	1,91	1,75
Big utility vans (e.g. VW Multivan)	5,15	1,93	2,06

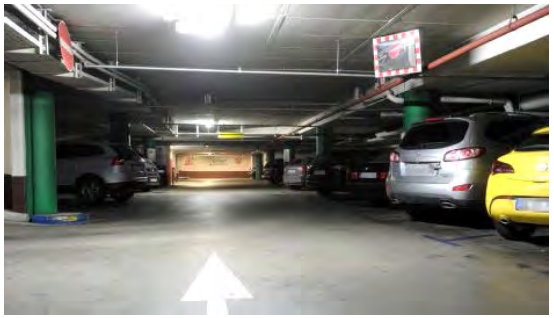
Source 3

- **Design vehicle:**

For users with no clearly defined special needs the design vehicle for a garage in central Europe – as an assumption based on the mentioned German data – is 1,84 m wide (without mirrors) and 4,77 m long.

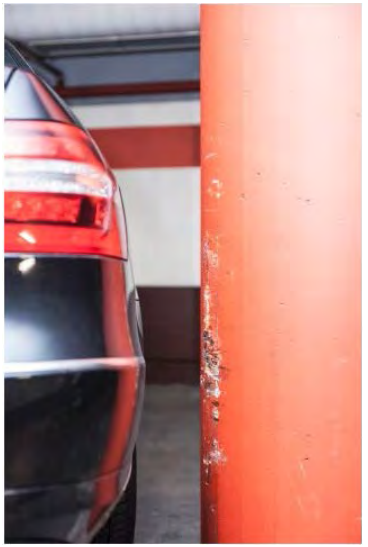
- **Content**
  1. Introduction
  2. Design vehicle
  3. Parking lots and lanes
  4. Headroom
  5. Ramps
  6. Queue length
  7. Construction of parking facilities
  8. Bicycle parking
  9. Loading docks

- **Parking lots and lanes:**
  - **What parking lots mostly look like:**



Source 6

Source 7



→ Parking spaces too narrow and short, dark, lanes and ramps too small

- **Parking lots and lanes:**
  - **Lanes should allow secure slow driving along and moving into and out of parking lots**
  - **To determine the necessary width of a lane the turning curve of cars, column grid of the garage construction and the angle of the lots have to be taken into consideration**
  - **Space for columns, walls, isolation and technical installations has to be added to the measurements of lots and lanes**
  - **construction grid of the building has to be adjusted with the grid of the garage if garage is underground**

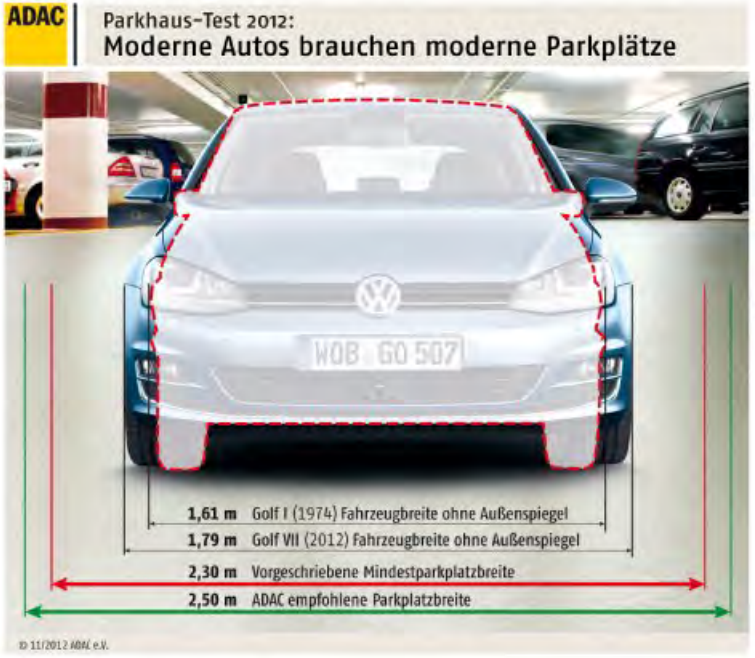
- **Parking lots and lanes:**
  - **Parking lots are still build this way due to old parking guidelines and regulations**
  - **Cars become bigger (q.v. design vehicle), but articles are not renewed → some still from the 70s**
  - **e.g. Hessische Garagenverordnung of 1995/ 2014:**

§ 5
Einstellplätze und Fahrgassen

(1) Ein Einstellplatz muss mindestens 5 m lang sein. Die Breite eines Einstellplatzes muss mindestens betragen

1. 2,30 m, wenn keine Längsseite,
2. 2,40 m, wenn eine Längsseite,
3. 2,50 m, wenn jede Längsseite des Einstellplatzes im Abstand bis zu 0,10 m durch Wände, Stützen, andere Bauteile oder Einrichtungen begrenzt ist,
4. 3,50 m, wenn der Einstellplatz für von Personen mit Behinderung nach § 2 Abs. 2 Satz 1 genutzte Kraftfahrzeuge oder für von Personen mit Kleinkindern nach § 2 Abs. 3 Satz 1 genutzte Kraftfahrzeuge bestimmt ist.

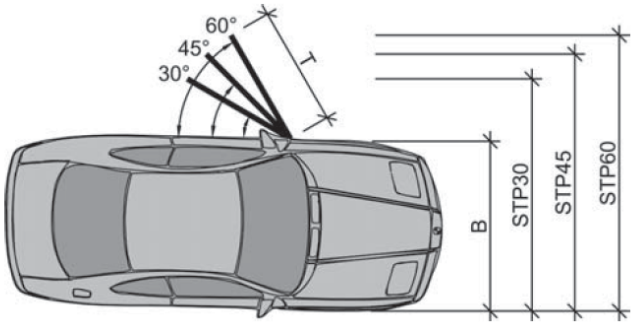
- **Parking lots and lanes:**
  - **State regulations define minimum requirements → investors tend to build minimum to maximize profit**
  - **In red: the minimum width of 2,30 m**
  - **In green: the recommended parking space width of 2,50 m**



Source 6

Parking lots and lanes: Width of Parking space and possibility to open the door

Width of Parking space [m]	impossible < 30° [%]	okay 30° [%]	comfortable 45° [%]	fully open 60° [%]
2,10	87	13	1	0
2,20	42	58	4	1
2,30	13	87	11	3
2,40	1	99	45	5
2,50	0	100	80	24
2,60	0	100	97	55
2,70	0	100	99	82
2,80	0	100	100	97



Source 8

Geometric design of bays and lots (federal D recommendation EAR 05):

Aufstellwinkel α [gon]	50	60	70	80	90	100
Fahrgassenbreite g [m]	3,00	3,50	4,00	4,50	5,25	6,00

Bay (5,00m length) at least 2,50m wide with lane at least 6,00m wide

Geometric design of bays and lots (European recommendation EPA):

4.9	Total unit measure of one way isle width and depth of two parking bays, depending on parking angle and bay width: Bay width: 2.50m / 2.45m / 2.40m / 2.35m / 2.30m 90° : 16.00 / 16.30 / 16.60 / 16.90 / 17.30 85° : 15.70 / 16.00 / 16.30 / 16.60 / 16.95 80° : 15.40 / 15.70 / 16.00 / 16.30 / 16.60 75° : 14.95 / 15.25 / 15.55 / 15.85 / 16.15 70° : 14.50 / 14.80 / 15.10 / 15.40 / 15.70 65° : 14.40 / 14.40 / 14.55 / 14.80 / 15.10 60° : 14.30 / 14.30 / 14.30 / 14.30 / 14.50 55° : 14.00 / 14.00 / 14.00 / 14.00 / 14.10 50° : 13.75 / 13.75 / 13.75 / 13.75 / 13.75 45° : 13.50 / 13.50 / 13.50 / 13.50 / 13.50

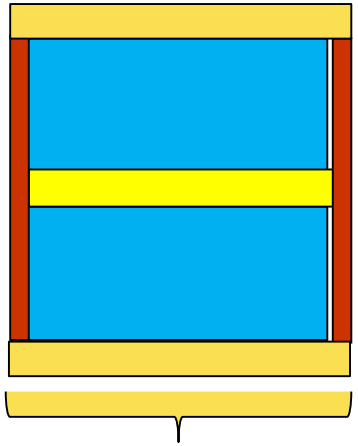
Bay (5,00m length) 2,50m wide with lane at least 6,00m wide

Bay (5,00m length) at least 2,30m wide with lane at least 7,30m wide

- **Parking lots and lanes:**
  - **Good example: parking garage Luisenplatz in Potsdam, Germany (winner of ADAC garage test)**
    - » **Big parking spots, wide lanes, light, good guidance through signs, enough headroom space etc.**

Source 6

Parking lots and lanes: standard pc

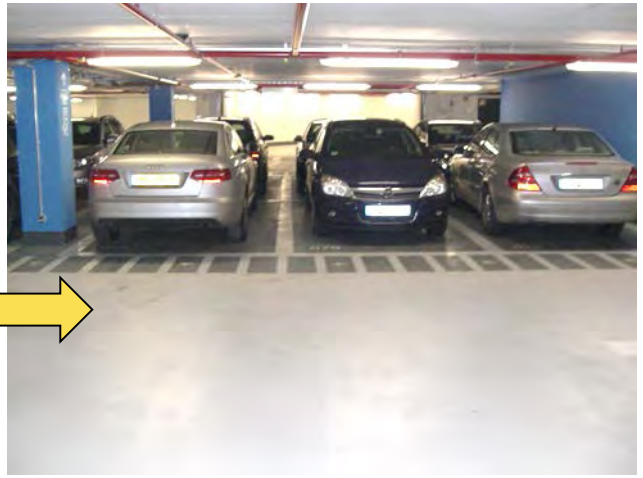


1.84m car

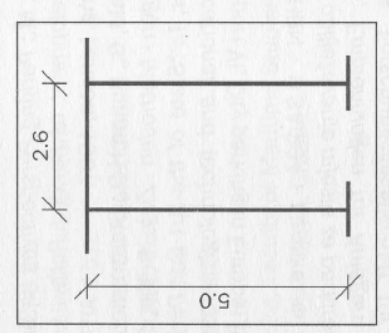
0.55m .. 0.75m → 0.65

2.50 m width

5.00 m length



0,10 .. 0,15 / 4,77m car/ 0,10 .. 0,15



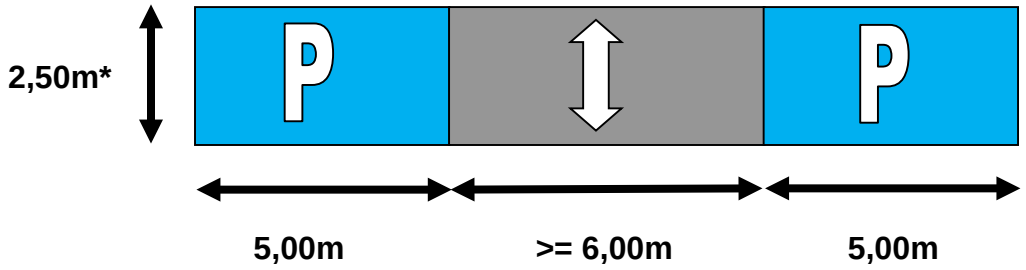
Croatia (Brcic et.al.):

1.85m car

+0.75m → 2,60m width

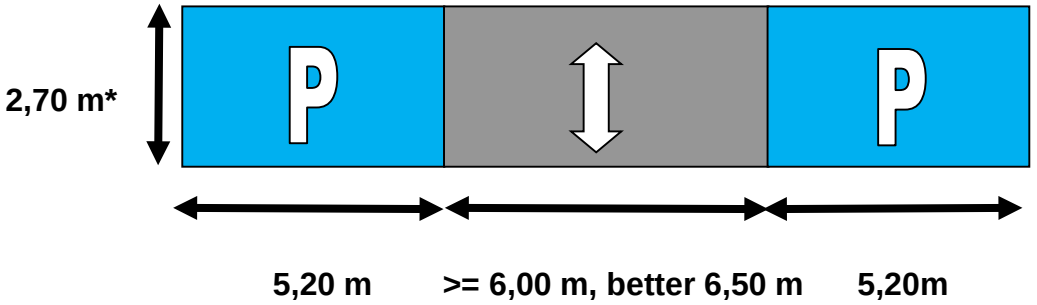
Source 14

- **Parking lots and lanes:**
  - **Standard pc:**



  - **Comfort pc:**

specially for upper class cars



*+25cm end bay: add. width or backwards

Parking lots and lanes: Geometry of lots and lane

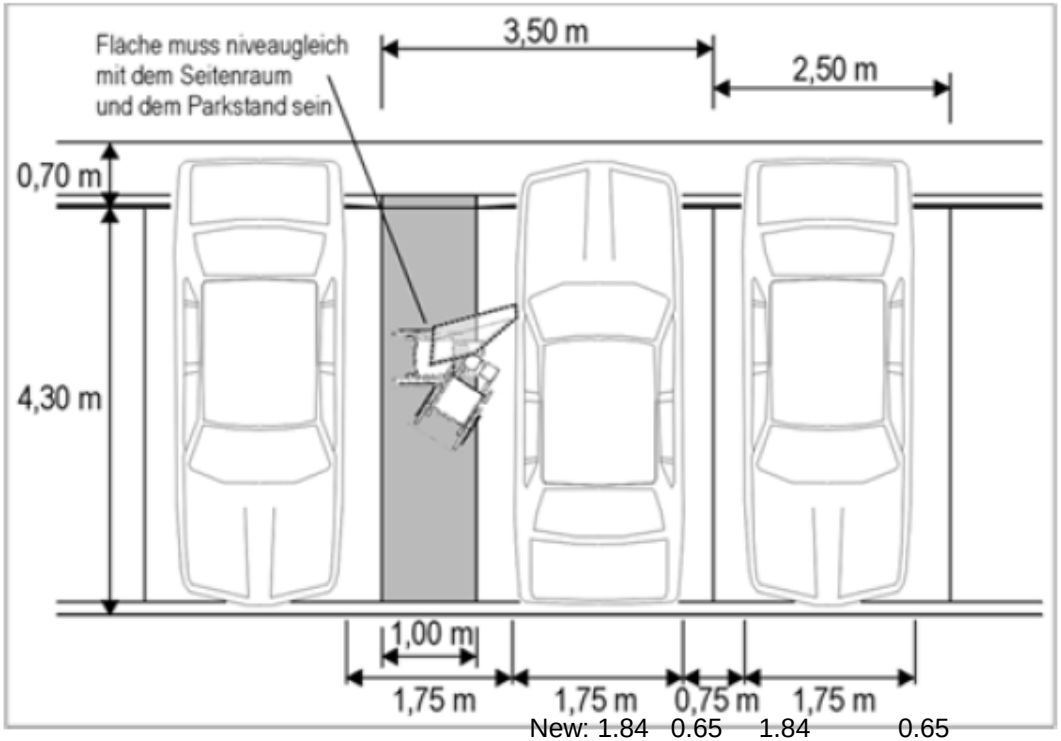
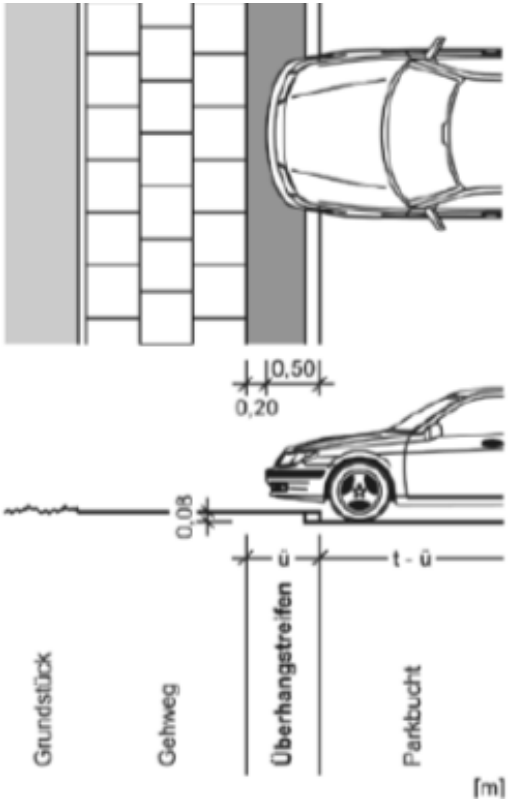
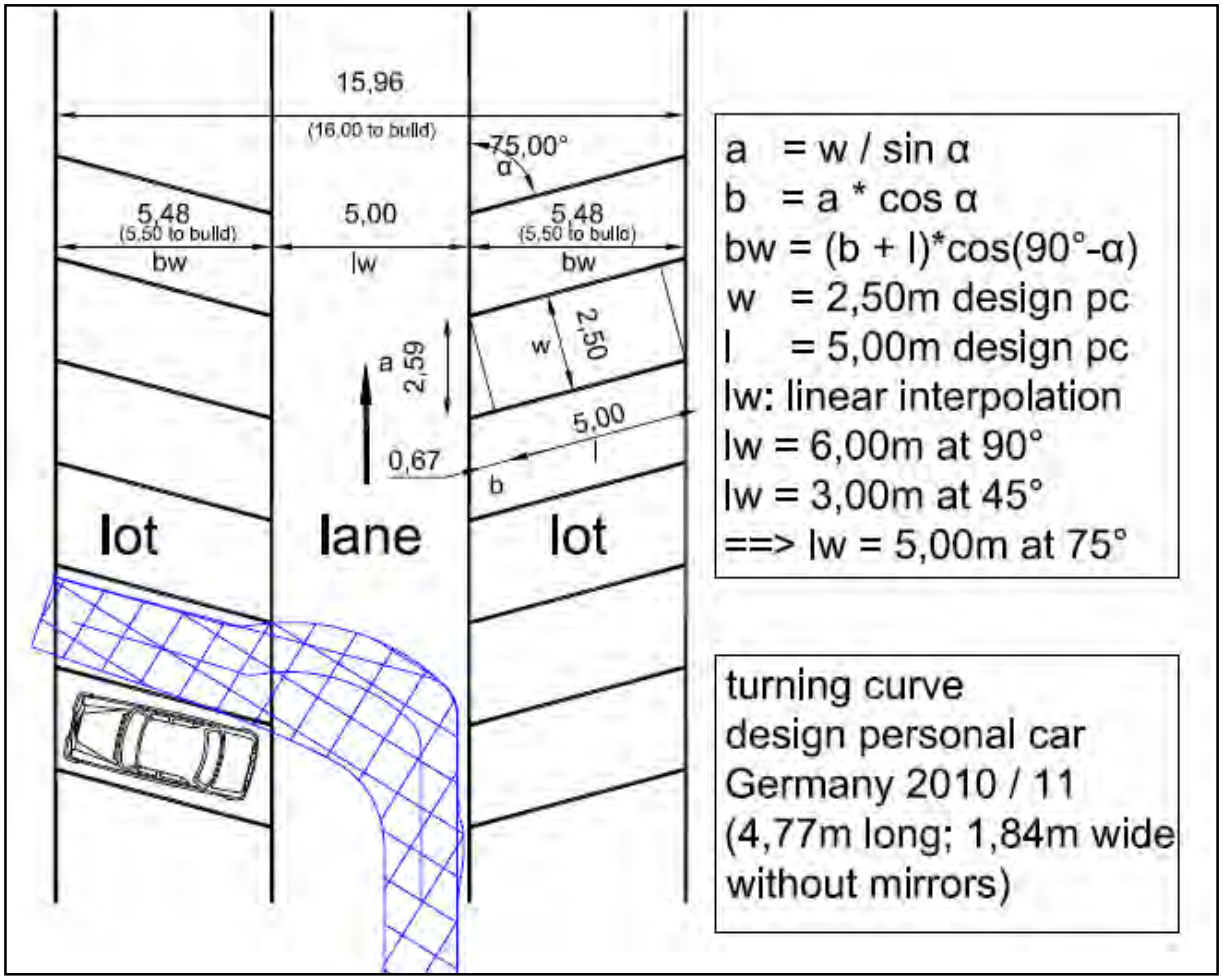


Bild 18: Grundmaße für das Abstellen des Bemessungsfahrzeugs Pkw

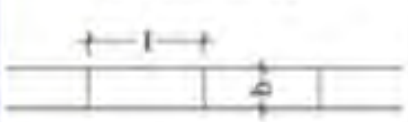
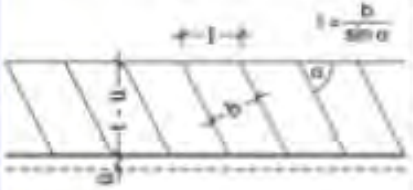
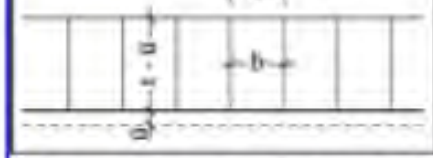


Source 13

Parking lots and lanes: Geometry of lots and lane



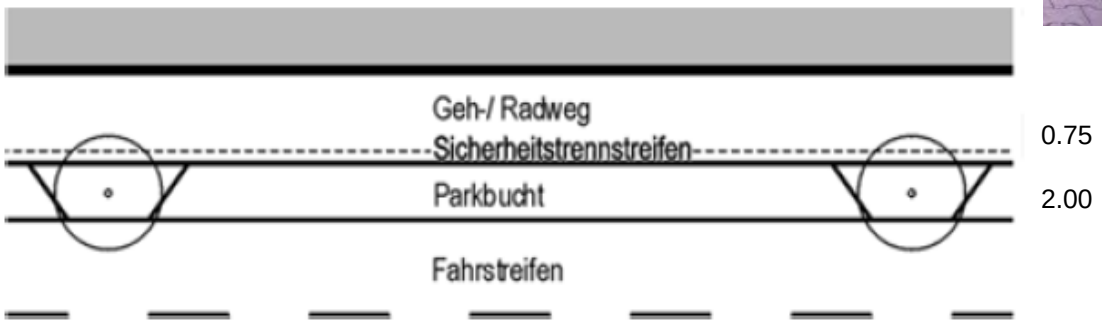
Parking lots and lanes: Geometry of lots and lane

	Aufstell-winkel α [gon]	Tiefe ab Fahrgassen-rand t – ū [m]	Breite des Überhang-streifens ū [m]	Breite des Park-stands b[1] [m]	Straßenfrontlänge l [m] beim Einparken		Fahrgassenbreite g [m] beim Einparken	
					vorwärts	rückwärts	vorwärts	rückwärts
Längsaufstellung 	0			2,00	6,70[2]	5,70 5,20[3]	3,25	3,50
Schrägaufstellung 	50	4,15	0,70	2,50	3,54		3,00	
	60	4,4[illegible]	0,70	2,50	3,09		3,50	
	70	4,[illegible]0	0,70	2,50	2,81		4,00	
	80	[illegible],65	0,70	2,50	2,63		4,50	
	90	4,55	0,70	2,50	2,53		5,25	
Senkrechtaufstellung 	100	4,30	0,70	2,50	2,50	2,50	6,00	4,50

[1] Besonderheiten siehe Abschnitt 4.2.2.1
[2] In Sonderfällen, z. B. um Behinderungen im Radverkehr beim Rückwärtseinparken zu vermeiden
[3] Durchschnittswert ohne Markierung

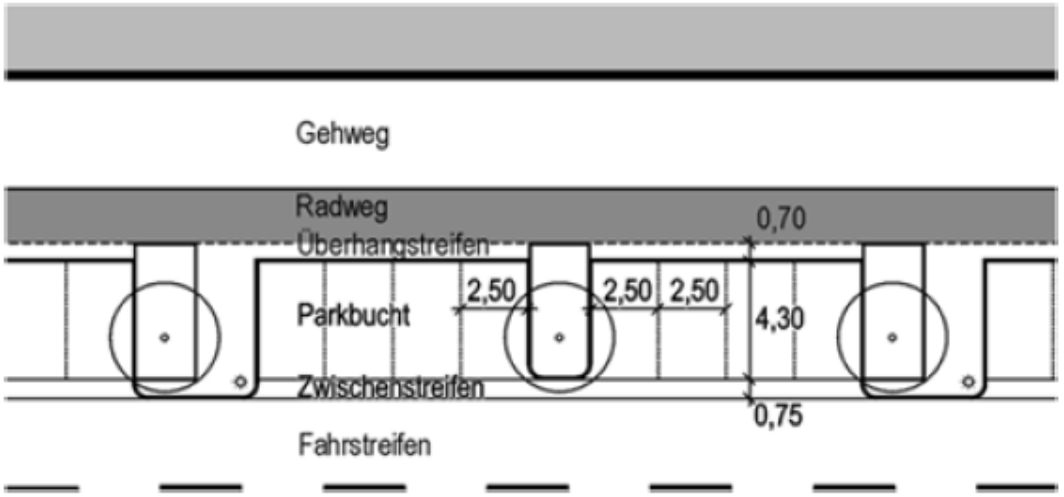
Source 12

Parking lots and lanes: lots and lane, longitudinal



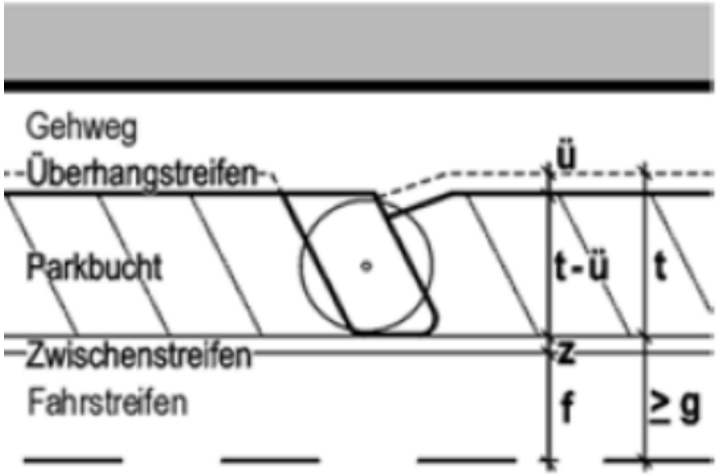
Source 13

Parking lots and lanes: lots and lane, 90° angled



Source 13

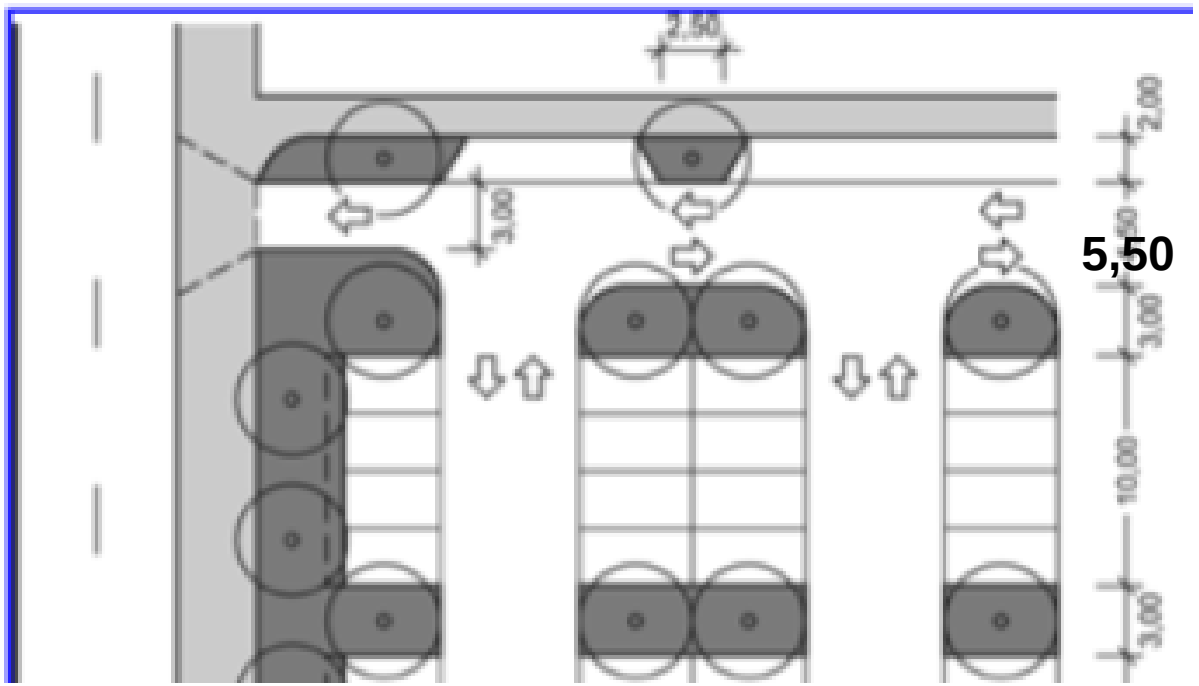
Parking lots and lanes: lots and lane, angled



t = f(α), see above

Source 13

Parking lots and lanes: lots and lane, adjacent



0.70-4.30-6,00- 10,00 -6,00 -5,00

Source 13, modified

Parking lots and lanes: lots and lanes, torture instruments of traffic planners

Parking lots and lanes: sight restrictions for p-lane

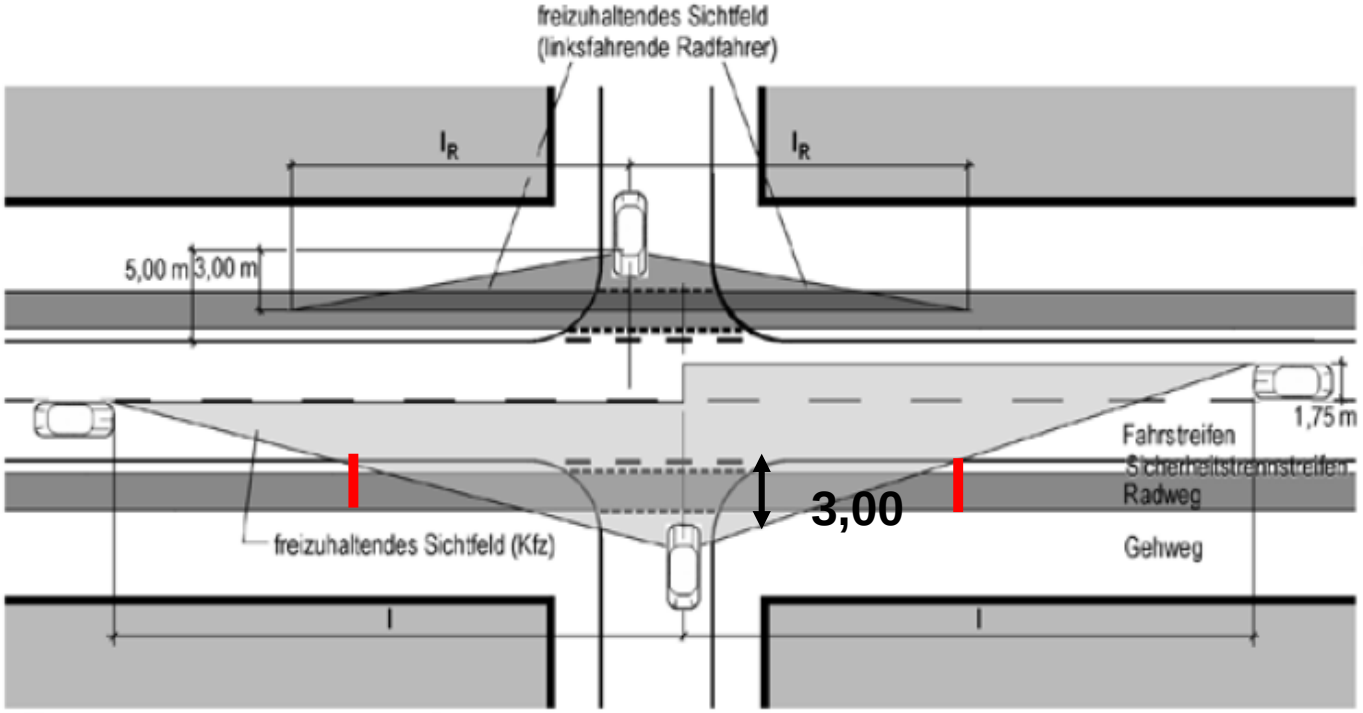
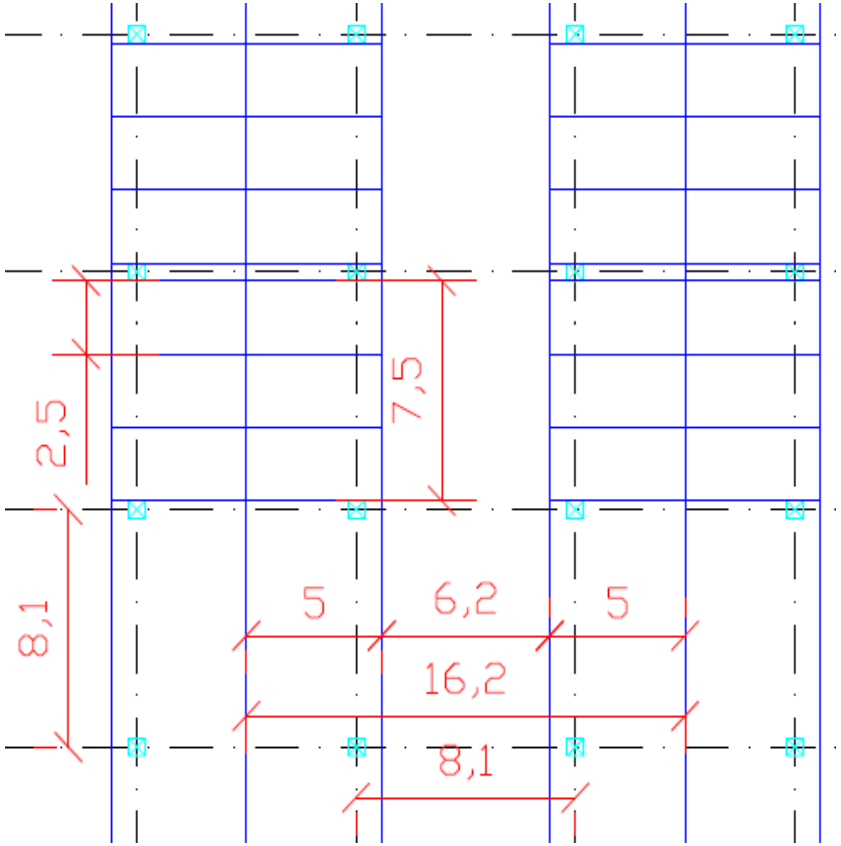


Bild 120: Sichtfelder auf bevorrechtigte Kraftfahrzeuge und Radfahrer

Eye-height: 1 m
l = 30m if v = 30 km/h
l = 70m if v = 50 km/h
lR = 20m minimum in town

Source 13

Parking lots and lanes: Good example (My Zeil Frankfurt):



8.10 = 6 x 1.35 common design grid

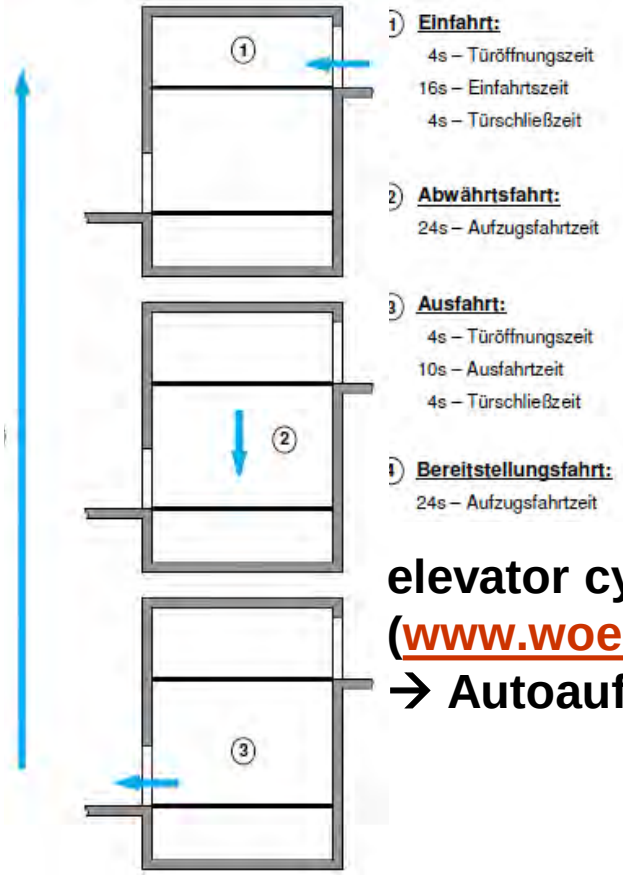
Parking lots and lanes: control with dynamic turning curves

Dyn turning curve big pc

Parking lots and lanes: mechanical parking system components

* Car elevators

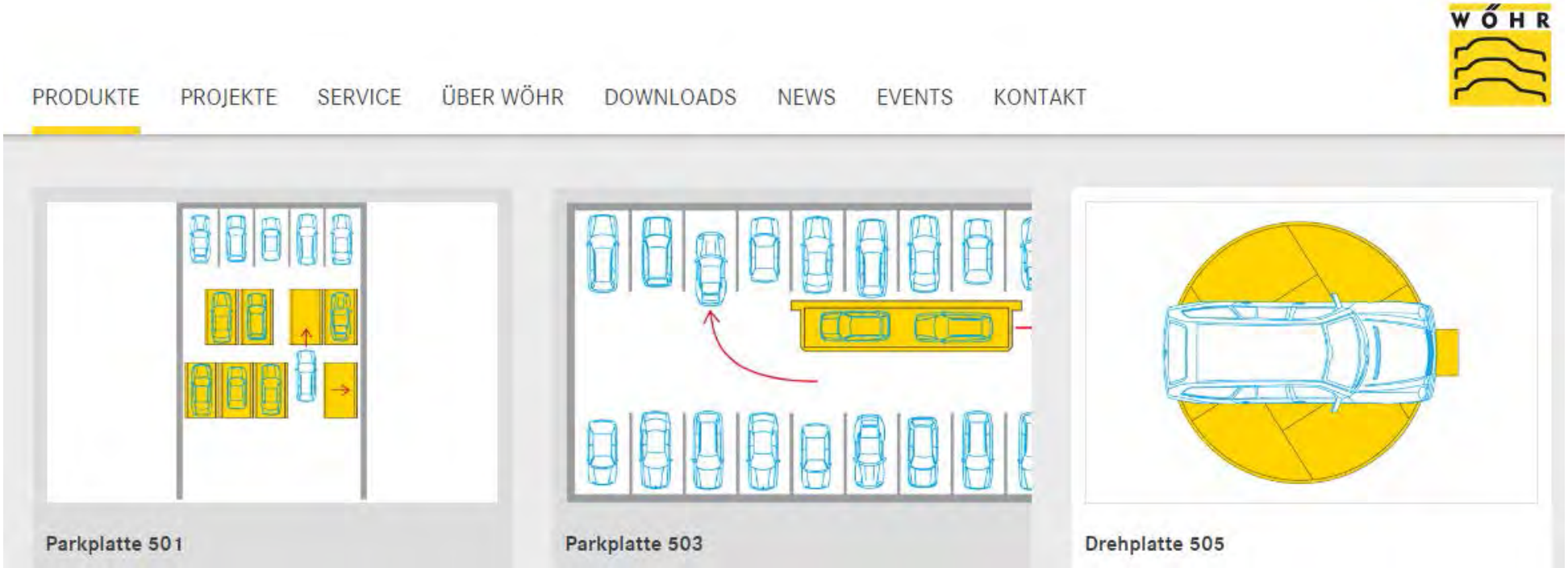
Elevator with turning platform
(www.berchtenbreiter-gmbh.de)



elevator cycle (7m): 90s
(www.woehr.de → Produkte
→ Autoaufzug)

Parking lots and lanes: mechanical parking system components

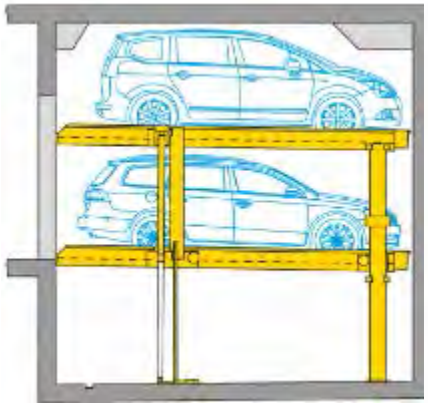
* Movable platforms

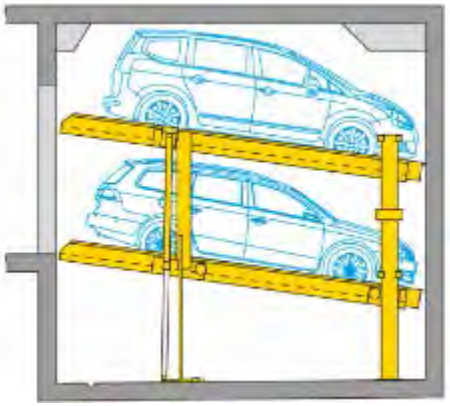


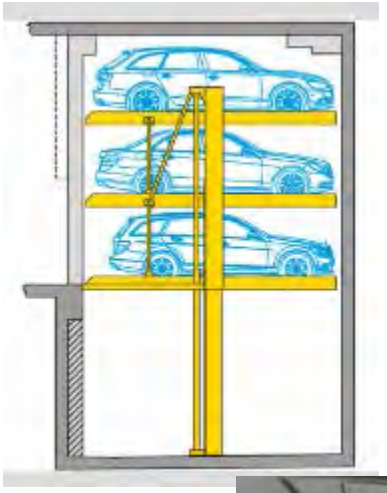
(www.woehr.de → Produkte → Parkplatten)

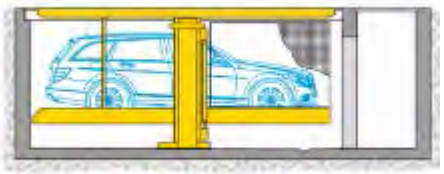
Parking lots and lanes: mechanical parking system components

* Parklift/ Combilift, self driving

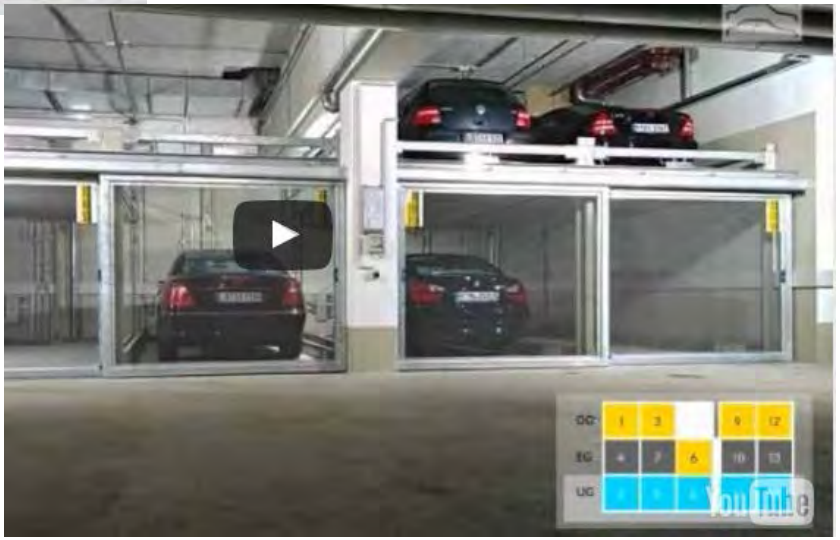








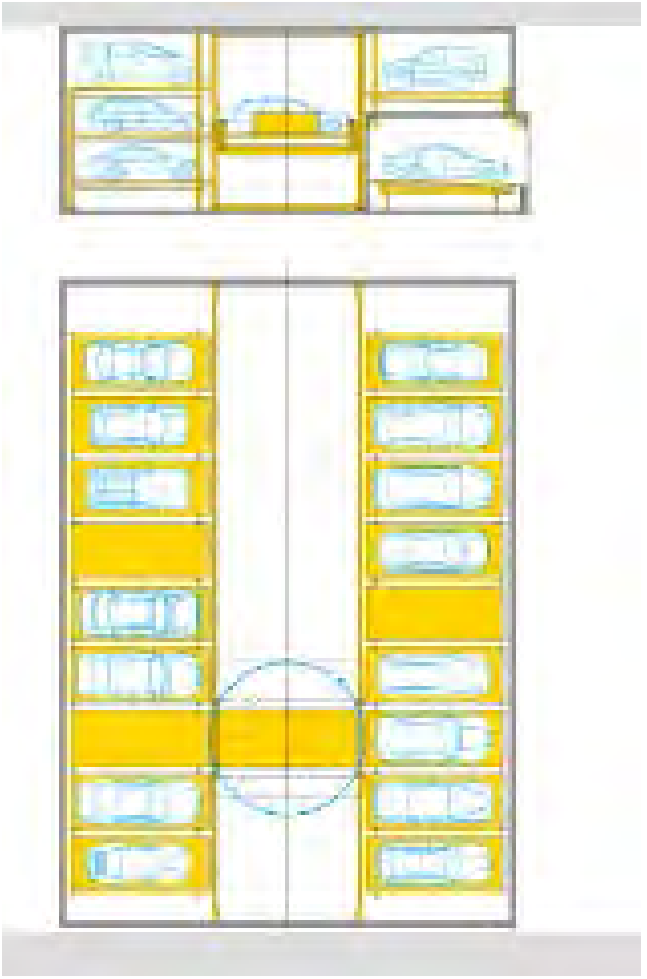
>=5,30m !



(www.woehr.de → Produkte
→ Combilift)

Parking lots and lanes: mechanical parking system components

* Car storage, automated



(www.woehr.de → Produkte → Multiparker)

- **Content**
  1. Introduction
  2. Design vehicle
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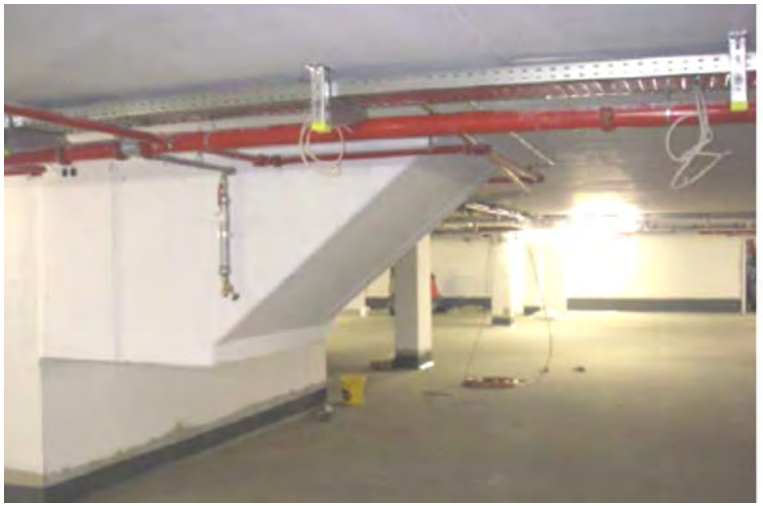
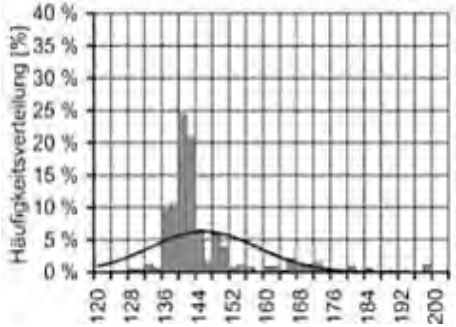
  4. Headroom
  5. Ramps
  6. Queue length
  7. Construction of parking facilities
  8. Bicycle parking
  9. Loading docks



Headroom



pc height distribution (source 8)

90% < 1,59m | 1% 1,95m … 2,00m, maximum VW Multivan 1,95m

Typical SUV ca. 1,80m (e.g. Porsche Cayenne) + roofrack ca. 40cm = 2,20m

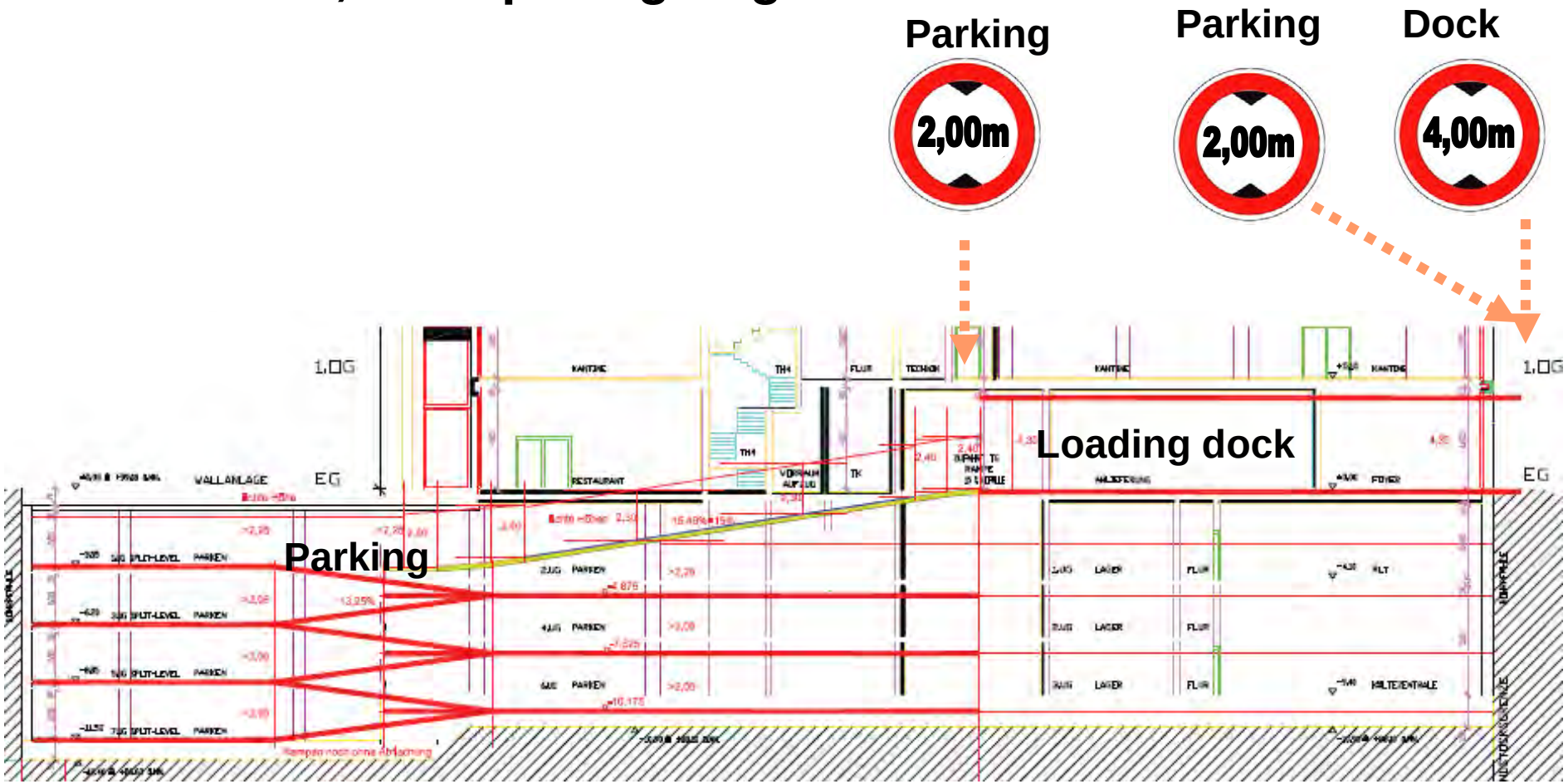
Headroom:

- has to be designed properly for ramps and parking levels
- Normally allowed height: 2,00 m, but cars are getting higher (e.g. SUV) → should be sign 2,10 m
- Sign at entrance has to show allowed maximum height; in addition hanging girder should warn if too high car tries to pass

Source 10

Source 9

Headroom; example signing at entrance



- **Headroom:**
  - **Tolerances have to be regarded:**
    - » **Actual height of car differs from height printed in car papers (e.g. tire pressure, suspension), can be 5cm**
    - » **Tolerance between calculated and build measures:**
      → 0,02 - 0,05 m (depending on national regulations)

→ At least 0,10 m tolerance should be added;
i.e. if entrance sign says 2,00 m, 2,10 m headroom needs to be planned at flat level

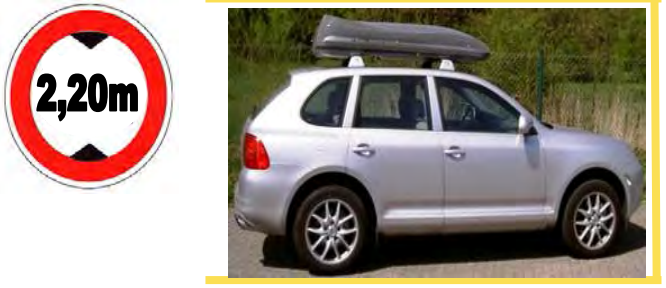
Headroom:
Recommended measure for headroom of bays and lanes

Signed height + 10cm reserve (on level) = construction height

A) standard level:

construction: >2,10m*

B) comfort level:



construction: >2,30m*

(* includes allowed building tolerance, depends on grid. E.g. DIN 18202: grid of 8,10m x 8,10m, construction headroom 2,05m → tolerance +/- 2 cm → headroom 2,03m … 2,07m; includes 5cm vehicle tolerance)

Headroom:

- Along slope ramps, more headroom is needed
  - » +0,05 m along the ramp → 2,15 m if 2,00 m is displayed
  - » +0,15 m where slope changes 8% or more (e.g. from 15% to 0%) at least along 1,50m (p.c.) at both sides of break of slope point → 2,25 m if 2,00 m is displayed

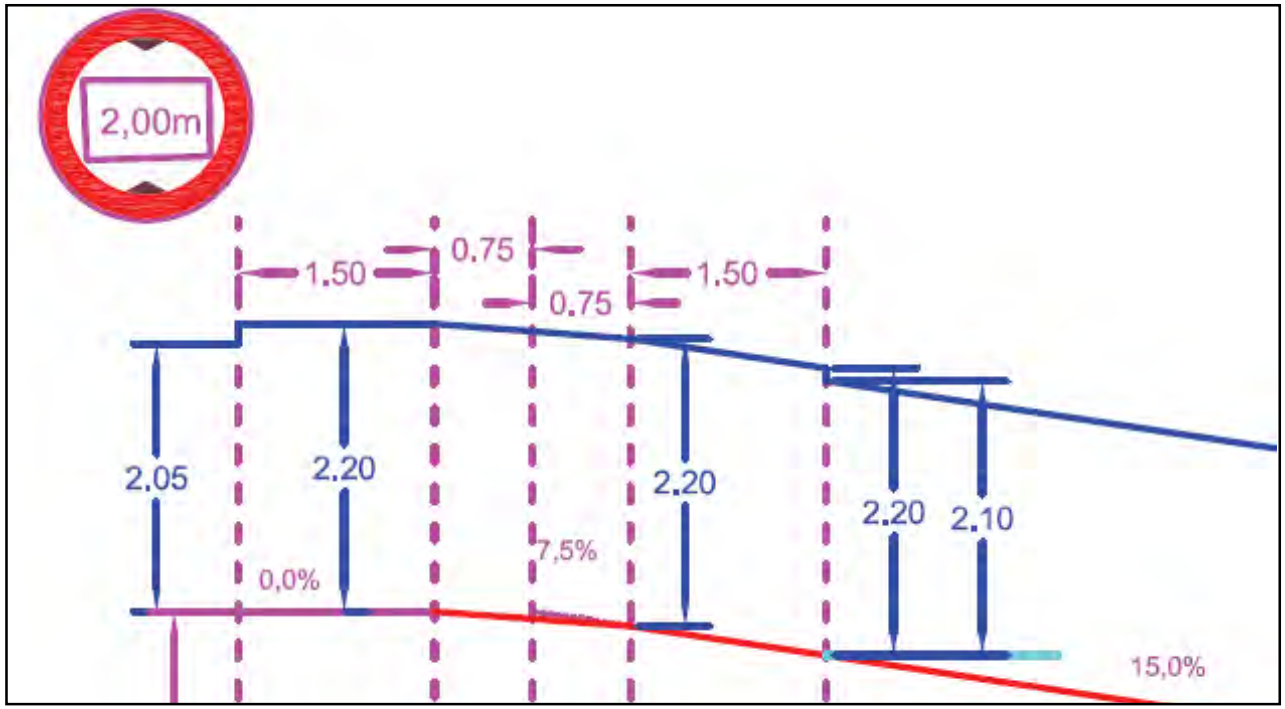
  (0,05 m for construction tolerance included!)

- Additional headroom can be necessary, if garage level is sloped for drainage (avoid puddles)

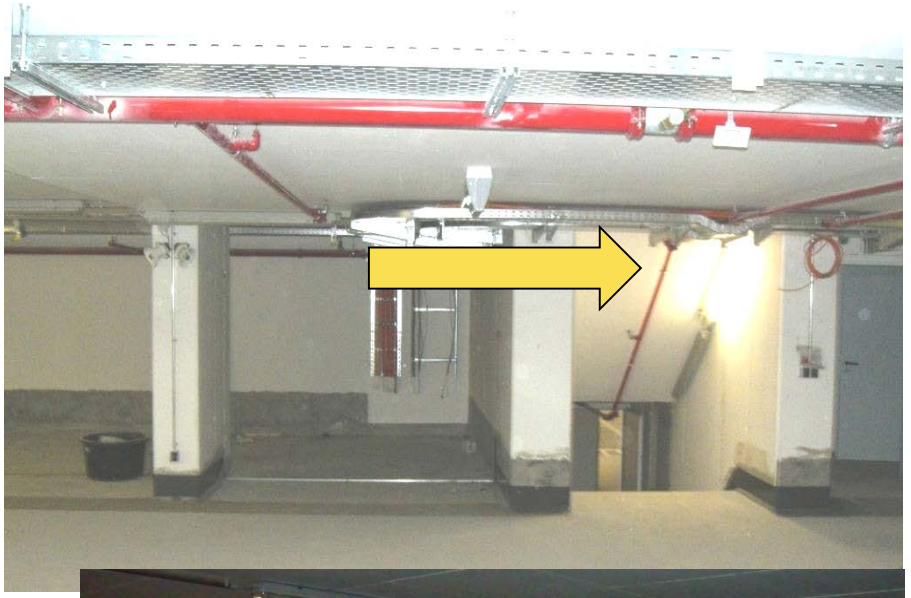
  → slope at least 2 % to ensure water flowing

Headroom:

- Example for calculating headroom along a garage ramp (5 cm construction tolerance excluded!)



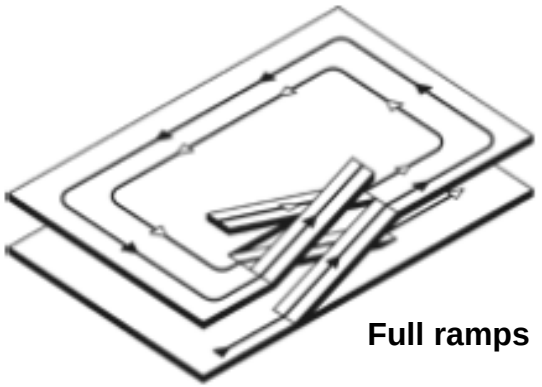
Headroom:



Headroom:

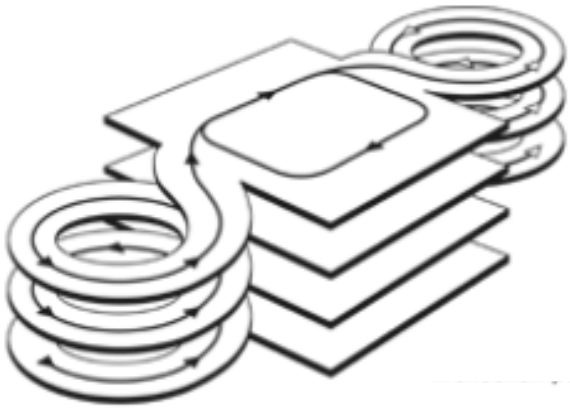
- **Content**
  1. Introduction
  2. Design vehicle
  3. Parking lots and lanes
  4. Headroom
  5. Ramps
  6. Queue length
  7. Construction of parking facilities
  8. Bicycle parking
  9. Loading docks

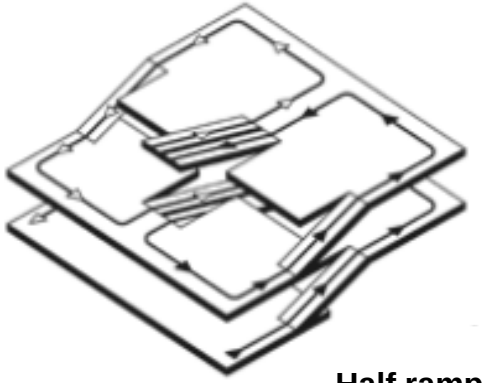
- **Ramps:**
  - **Different types of ramps:**



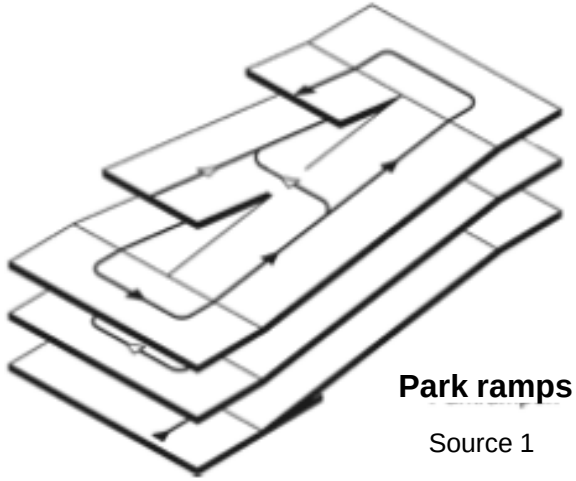
Full ramps

Spiral ramps





Half ramps

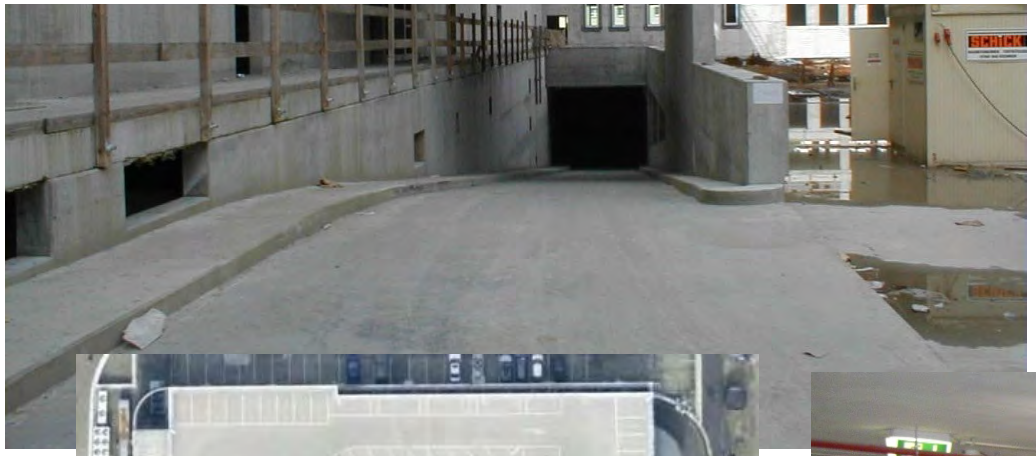


Park ramps

Source 1

Ramp = Garage element to change levels up or downwards

Ramps: full ramp



Police hq Frankfurt

Opernturm Frankfurt

Top level garage Wiesbaden (google earth)

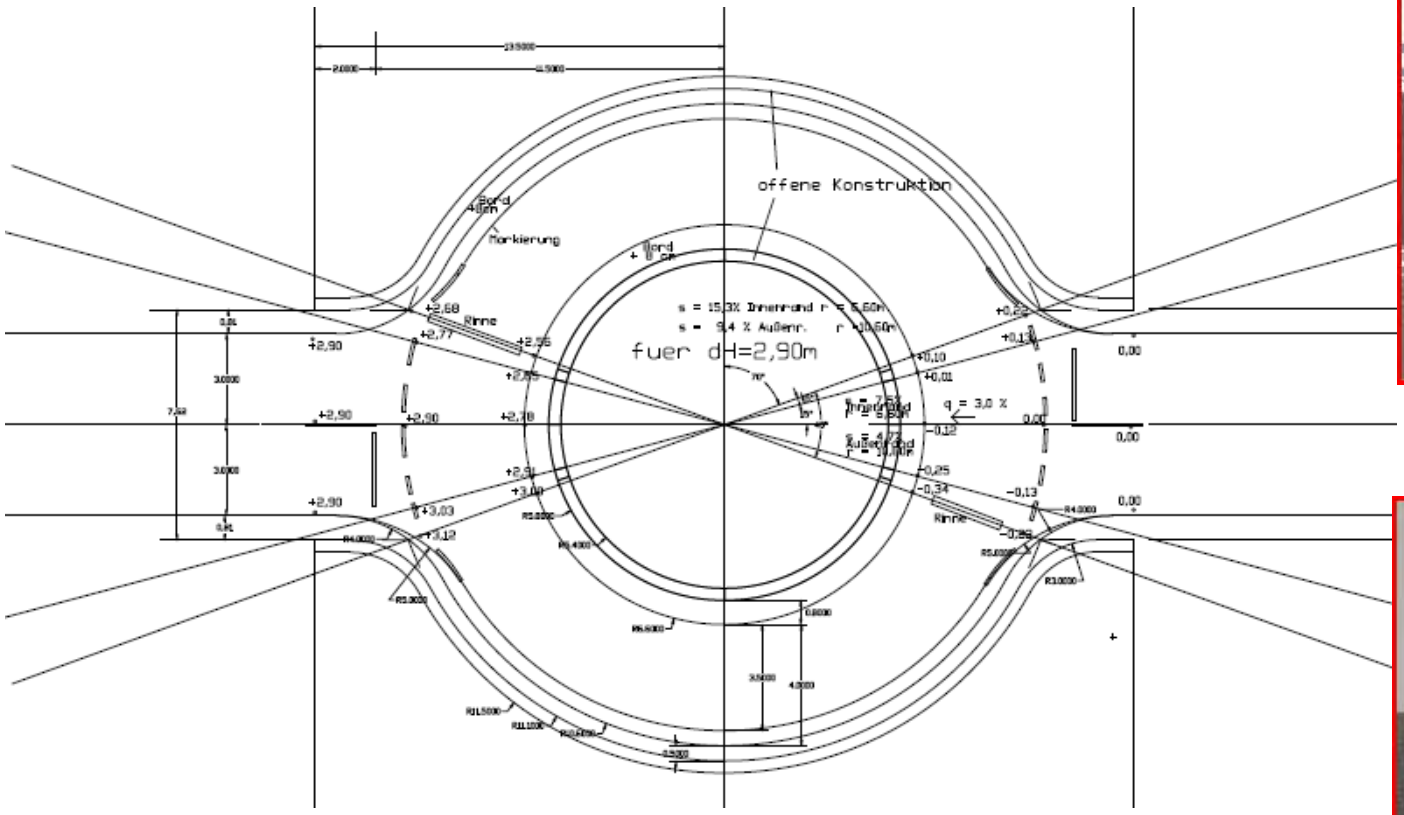
Ramps: spiral ramps

Double sp. ramp Poseidon Haus F

Double sp. ramp Frankfurt fair (helix)

Ramps: spiral ramps

Double sp. ramp Frankfurt fair (helix)

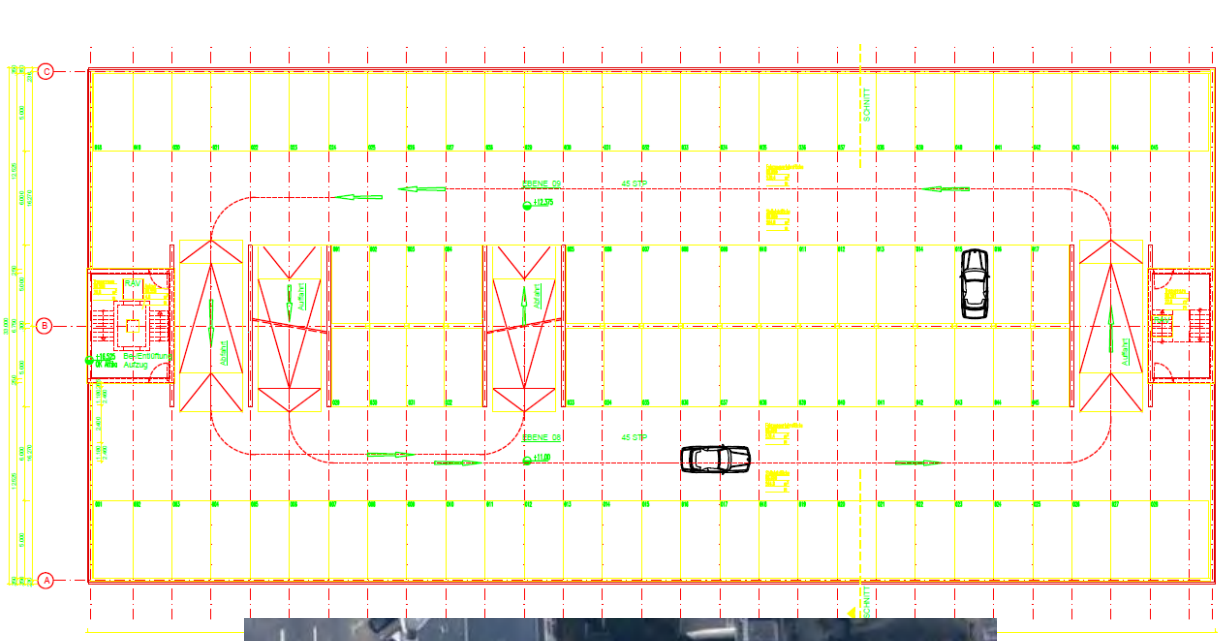


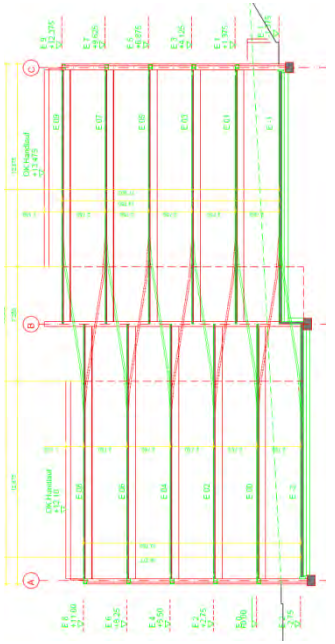
Ramps: spiral ramps

Single spiral ramps (EDEKA store, Frankfurt)

Ramps: split level ramp

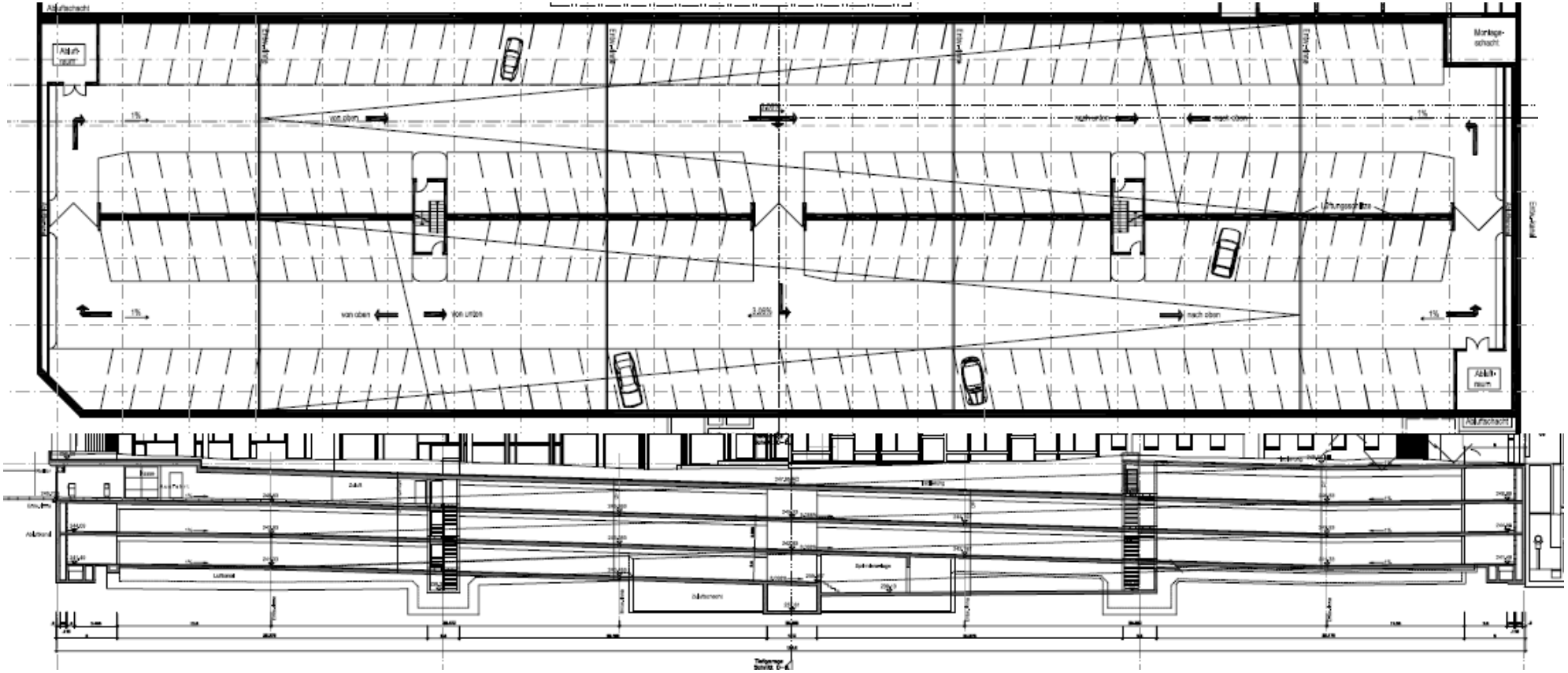
Example GOLDBECK system





Top level garage Wiesbaden (google earth)

Ramps: park ramp (library Stuttgart)

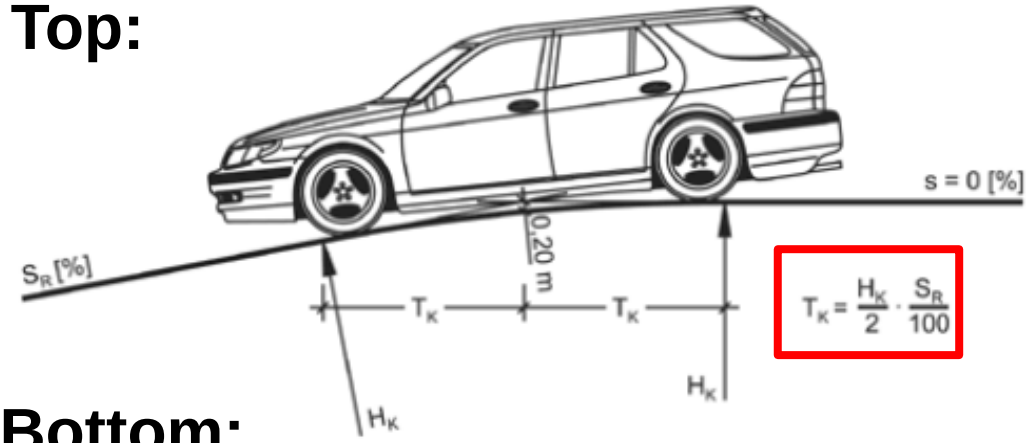


Ramps: park ramp (theatre Wiesbaden)

- **Ramps:**
  - **Longitudonal slope should not exceed 15 % (in the middle of the respective lane)**
  - **short ramps inside a garage may be sloped up to 20 % (but is not according to some regulations)**
  - **If the slope difference (+ to -) is more than Δs = 8 %, a flatter section with ½ s for 1,5 m at the top and 2,5 m at the foot of the ramp has proved to be sufficient to avoid car damages. More comfortable are vertically curved sections at top and bottom (H>=15m for pc; H>=50m for lorries).**

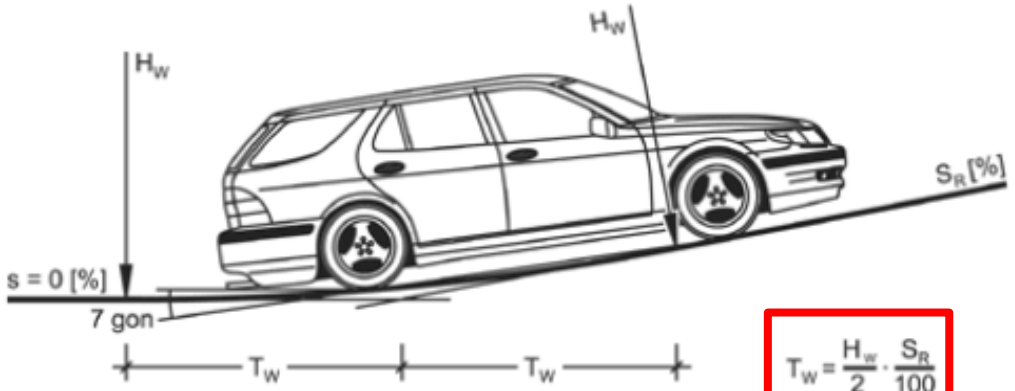
Ramps: Detail top and bottom with vertical curve

Top:



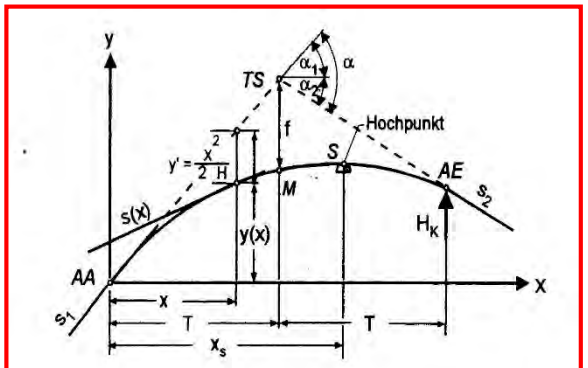
$$T_K = \frac{H_K}{2} \cdot \frac{S_R}{100}$$

Bottom:



$$T_W = \frac{H_W}{2} \cdot \frac{S_R}{100}$$

Source 1



Berechnung der Kuppen- und Wannenausrundungen

$$x_s = -\frac{s_1}{100} \cdot H \quad [m]$$

$$s(x) = s_1 + \frac{x}{H} \cdot 100 \quad [\%]$$

$$y(x) = \frac{s_1}{100} \cdot x + \frac{x^2}{2 \cdot H} \quad [m]$$

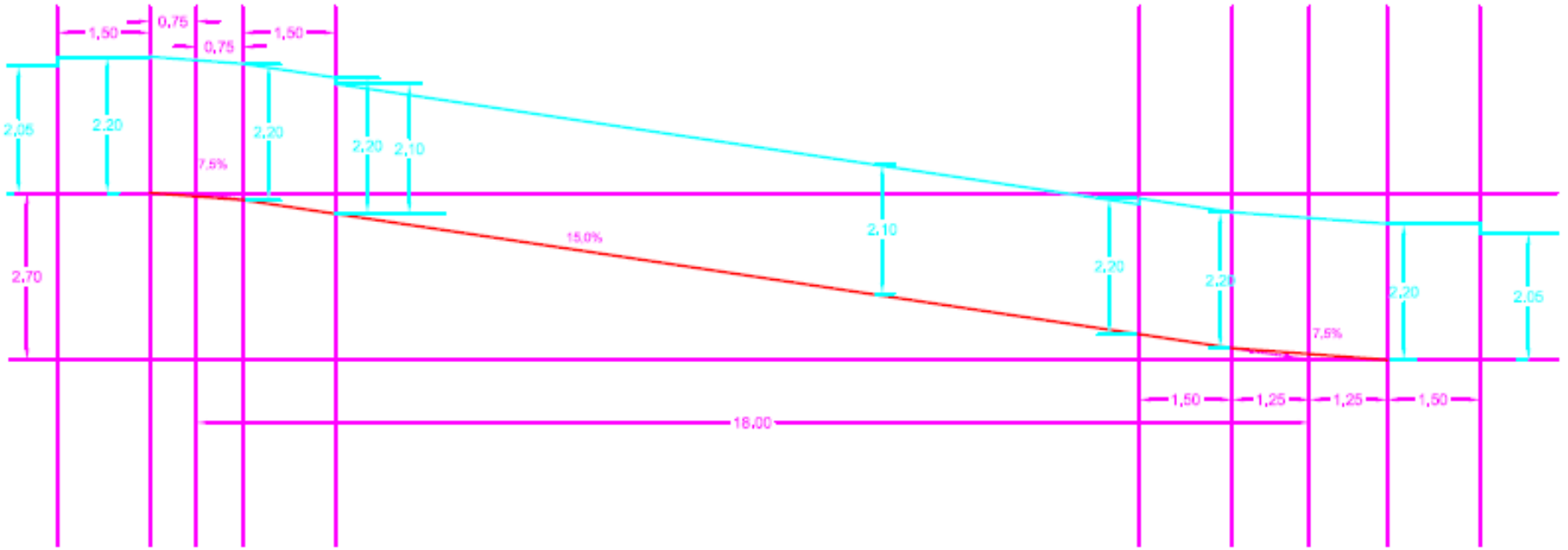
$$T = \frac{H}{2} \cdot \frac{s_2 - s_1}{100} \quad [m]$$

$$f = \frac{T_2}{2 \cdot H} = \frac{T}{4} \cdot \frac{s_2 - s_1}{100} = \frac{H}{8} \cdot \left(\frac{s_2 - s_1}{100}\right)^2 \quad [m]$$

Vorzeichenregel:
Steigung : positiv (z. B. s_1 = + 4,0 %)
Gefälle : negativ (z. B. s_1 = - 2,0 %)
Wannenhalbmesser (H_W): positiv (z. B. H = + 2000 m)
Kuppenhalbmesser (H_K) : negativ (z. B. H = - 3000 m)

Ramps: Detail top and bottom with ½ slope (no building tolerance included)

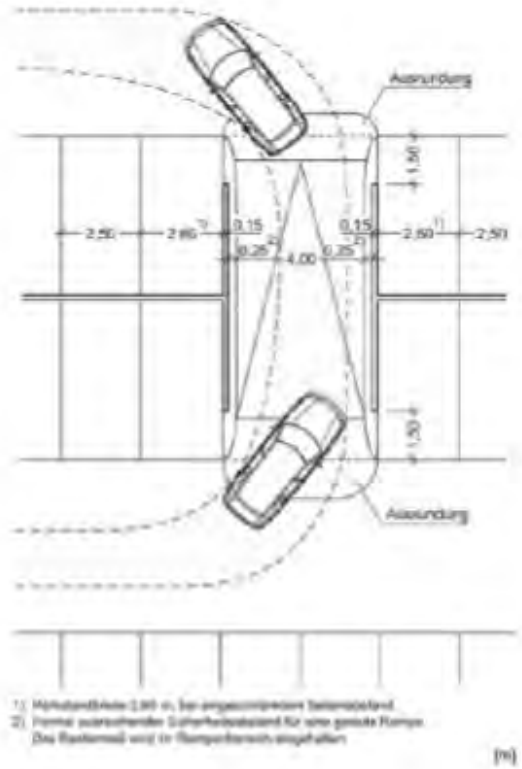
Lichtraum (hellblau) (fertig, ohne Bautoleranzen) bei Beschilderungshöhe 2,00m
Rampe 15% mit Abflachungen 7,5% gem EAR05, Geschosshöhe 2,70m



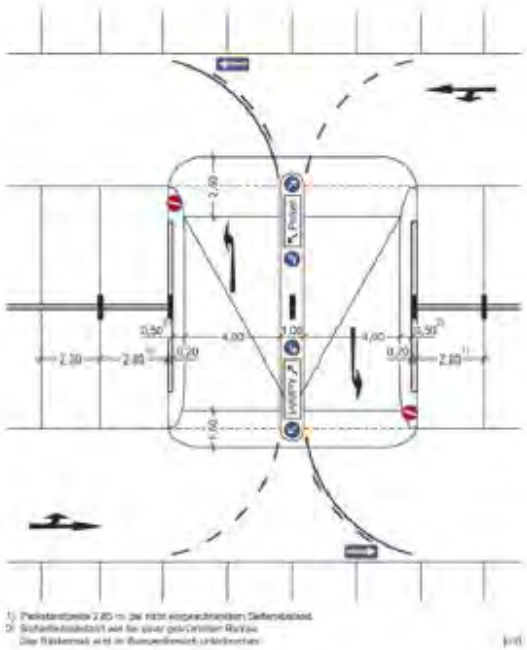
Source 1

- **Ramps:**
  - **horizontal design of a ramp has to comply with the turning curves of the chosen design vehicle + clearance to allow comfortable and secure driving**
  - **Linear ramps: min. lane width: 2,75 m + 0,25 m clearance on both sides**
  - **Curved ramps: min. radius: 5,00 m at the inner lane boundary; min. lane width: 3,50 m + 0,25 m clearance on both sides (Some sources demand for 3,70 m lane plus 30 - 50 cm clearance for more comfortable driving)**

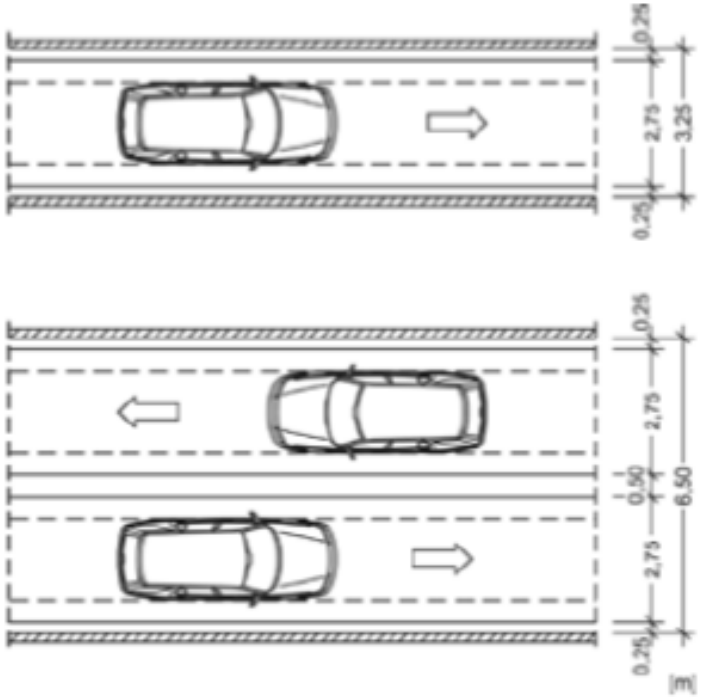
Ramps: recommendation EAR 05 (source 1)



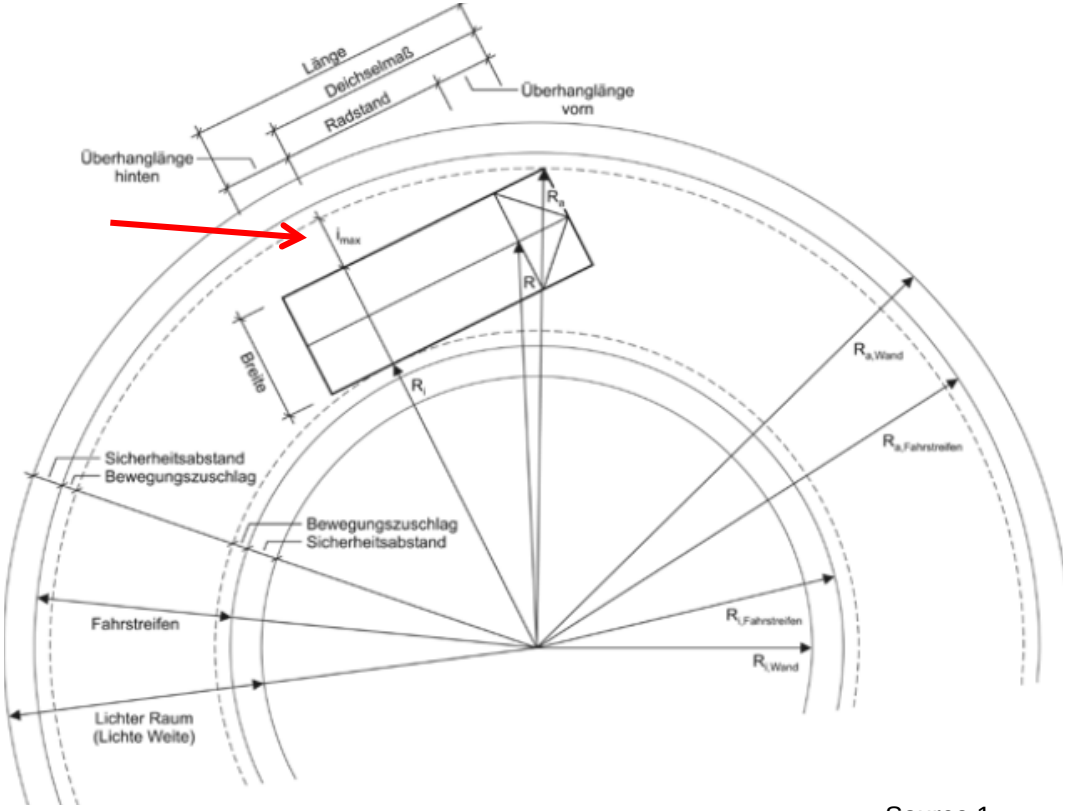
ir eine Halbrampe mit Einrichtungsverkehr



ild 4.5-5: Beispiel für eine Halbrampe mit Zweirichtungsverkehr als Linksverkehr



- **Ramps:**
  - **Calculation of the additional needed space:**



Maximum enlargement:

$$i_{max} = R_a - \sqrt{R_a^2 - D^2}$$

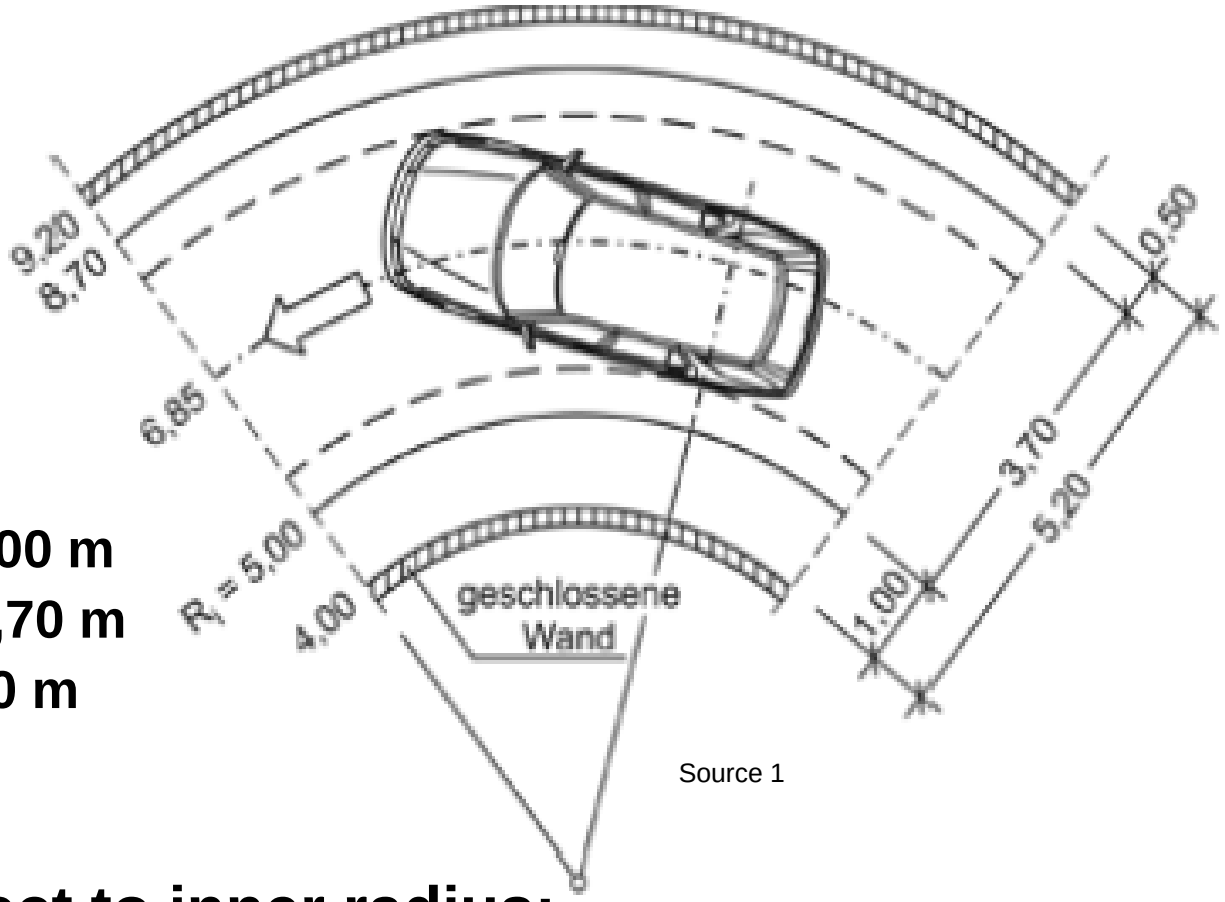
Approximately:

$$i_{max} \approx \frac{D^2}{2 \cdot R}$$

i_{max} [m]: maximum enlargement
R_a [m]: outer radius
R [m]: radius of middle of front axle
D [m]: measure of the drawbar

Source 1

- **Ramps:**
  - **Recommended**
    - **Inner Radius: 5,00 m**
    - **Outer Radius: 8,70 m**
    - **Lane Width: 3,70 m**



Source 1

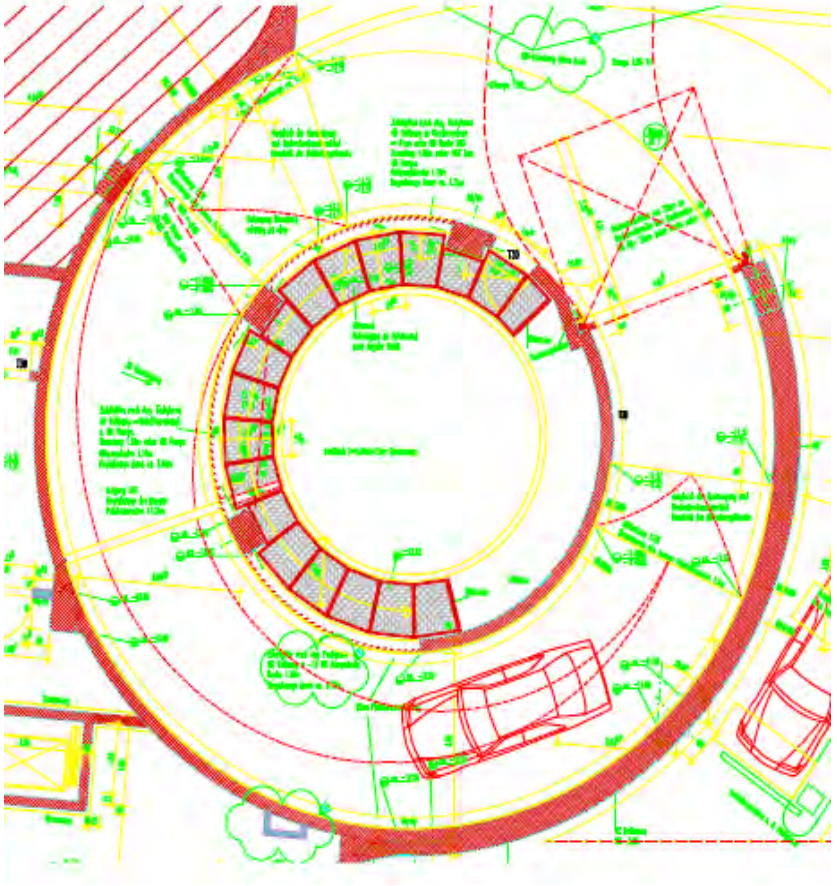
  - **Lane width subject to inner radius:**

R_i [m]	5,0	6,0	7,0	8,0	9,0	10,0	12,0	14,0	16,0	18,0	20,0
f [m]	3,70	3,60	3,50	3,45	3,40	3,35	3,25	3,15	3,10	3,05	3,00

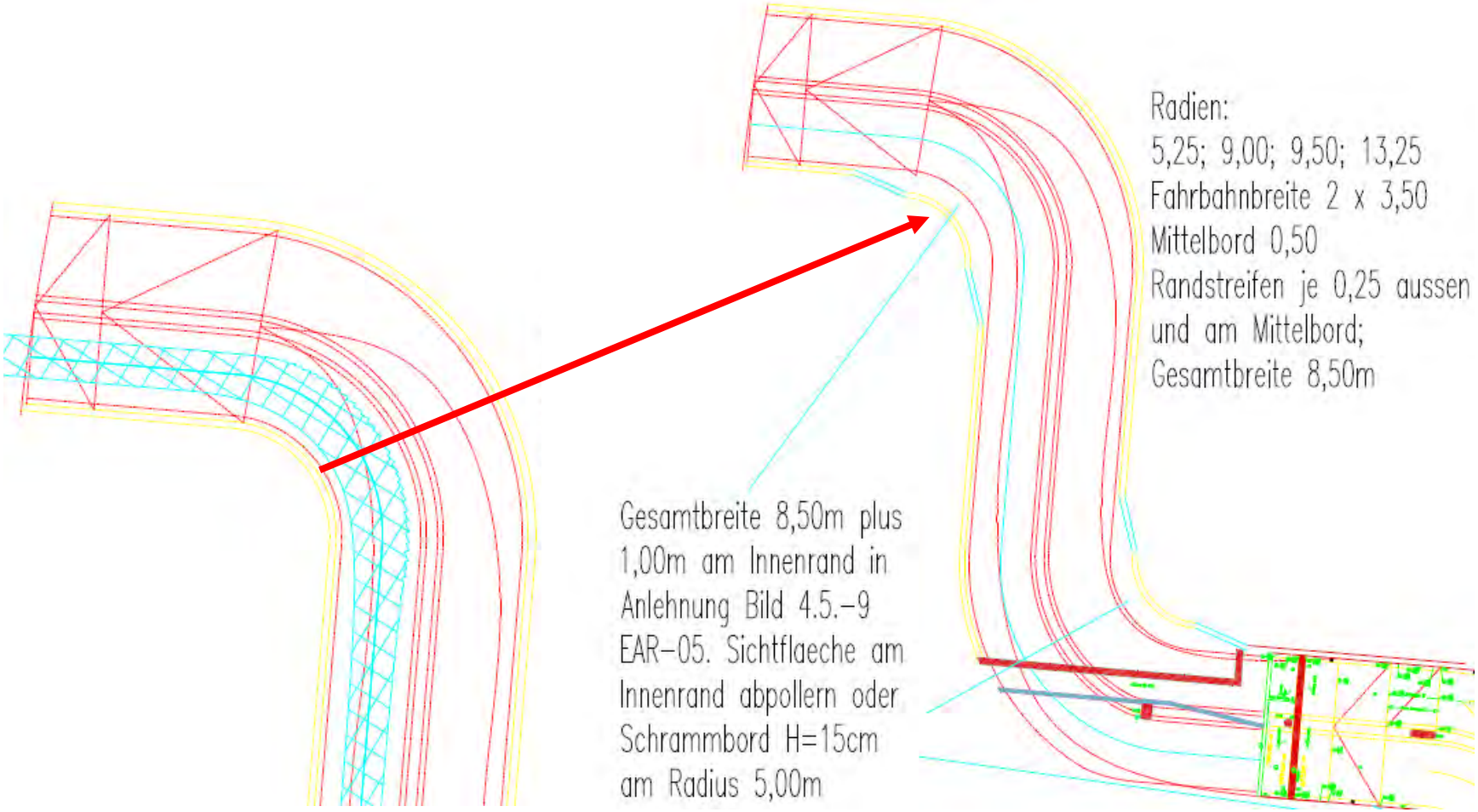
Source 1

Ramps:

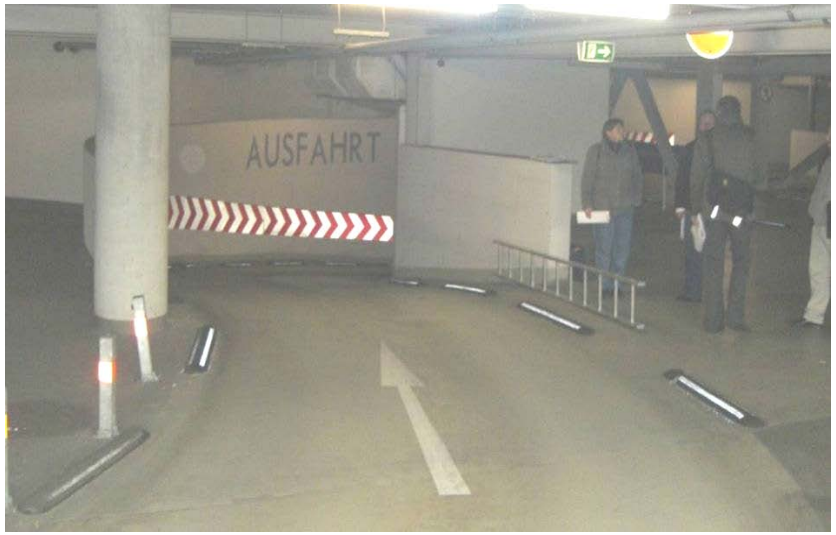
Example spiral ramp: R=5,00m; R=8,50m + 2x25cm curb
Total width 4,00m → no problem (My Zeil garage Frankfurt)



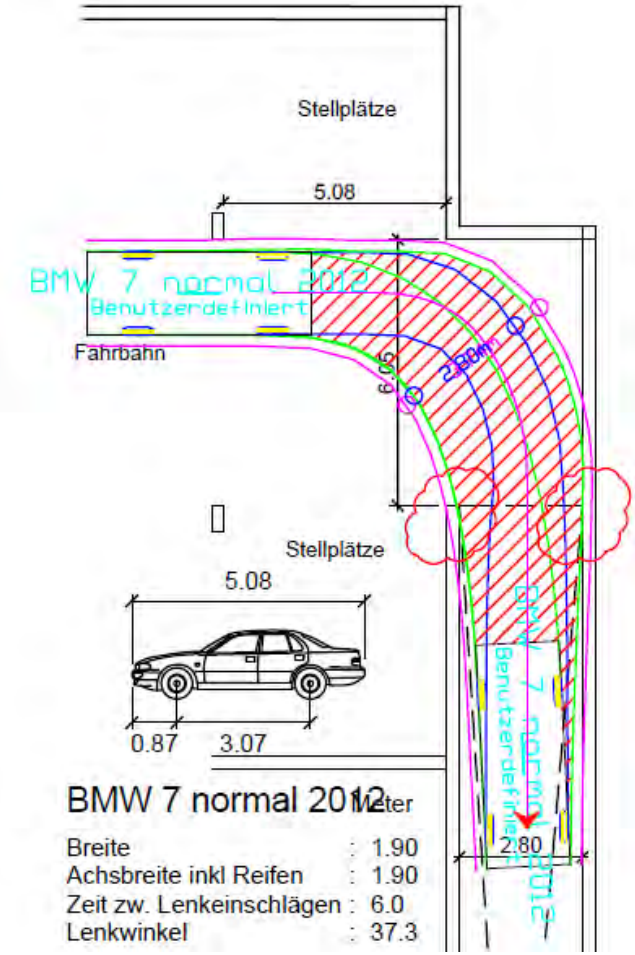
Ramps: Example 2-lane ramp (My Zeil Frankfurt)

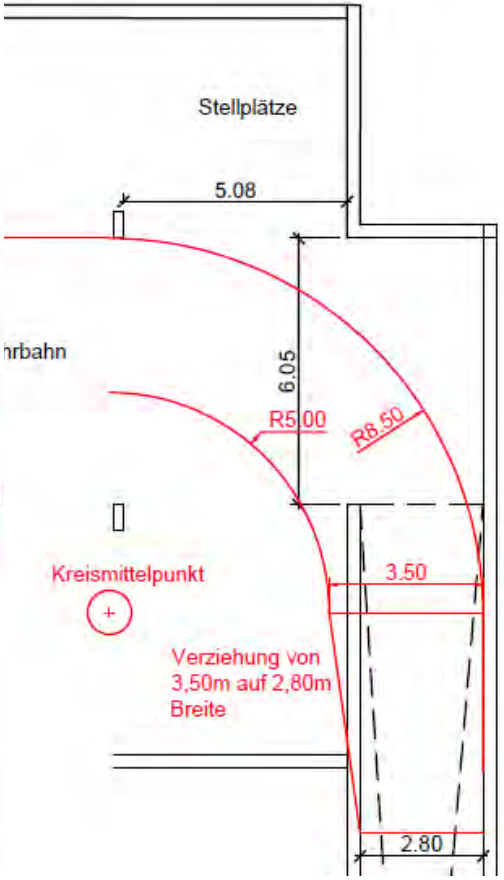


- **Ramps: Bad example: ramp very narrow, no adaptation segment between curve (Ri=5,00m, width 3,50m) and straight lane (width 2,75m)**
- **Adaptation segment should be >= 5m long**



- **Ramps: ramp very narrow, no adaptation >=5m**

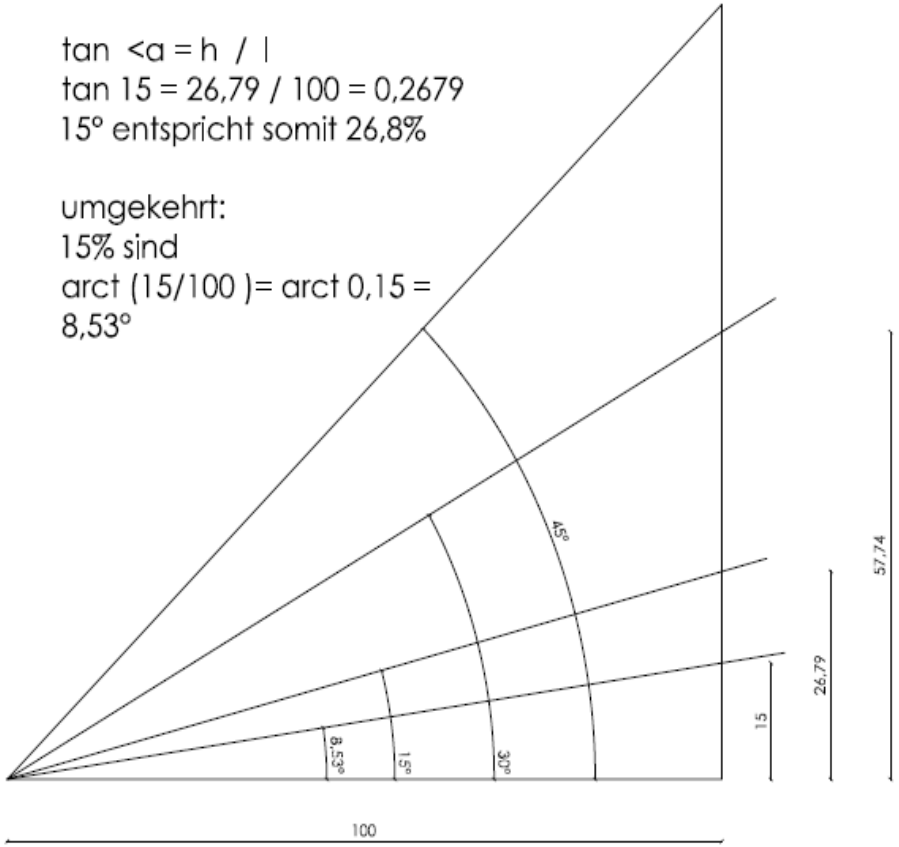


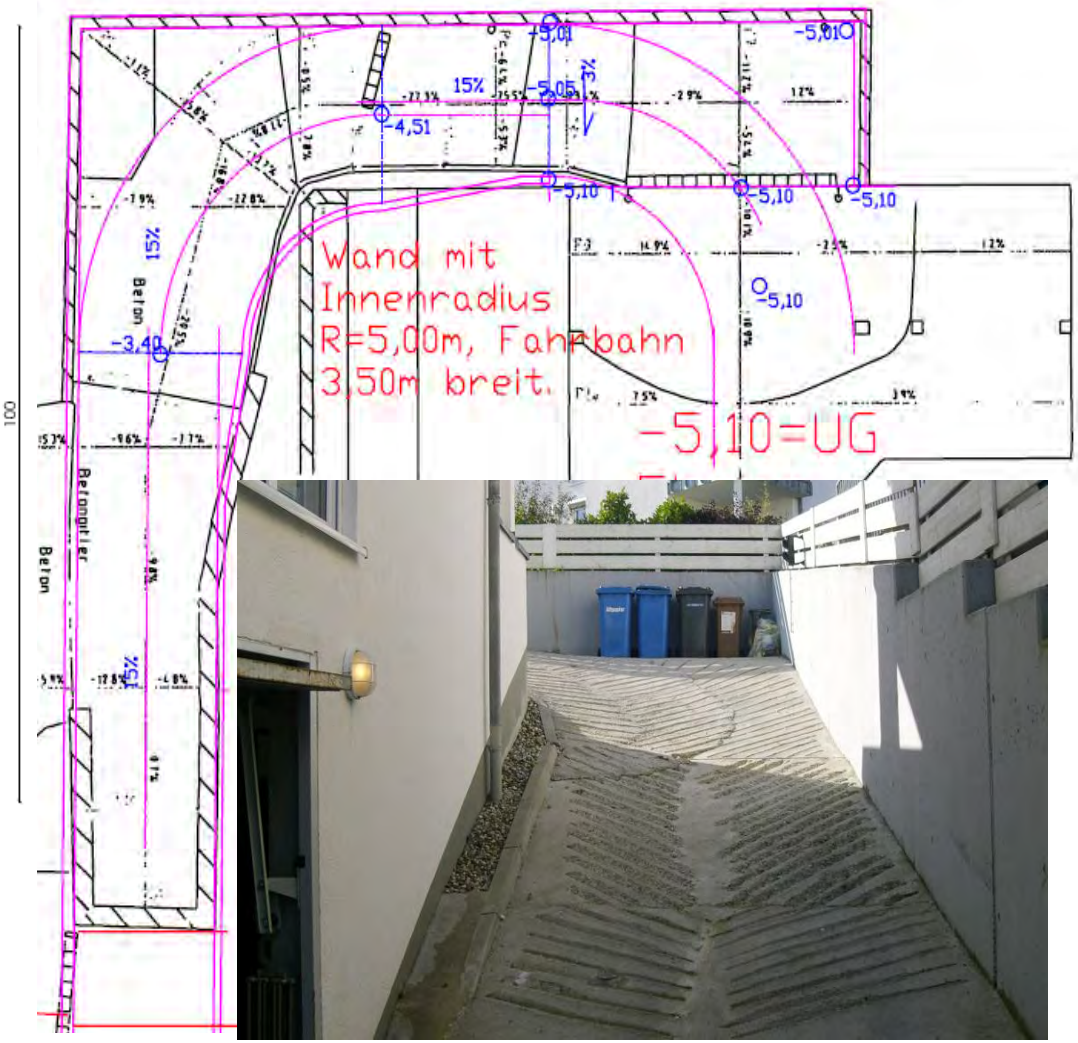


Ramps: Bad example short ramp (built 15° instead of 15%!)

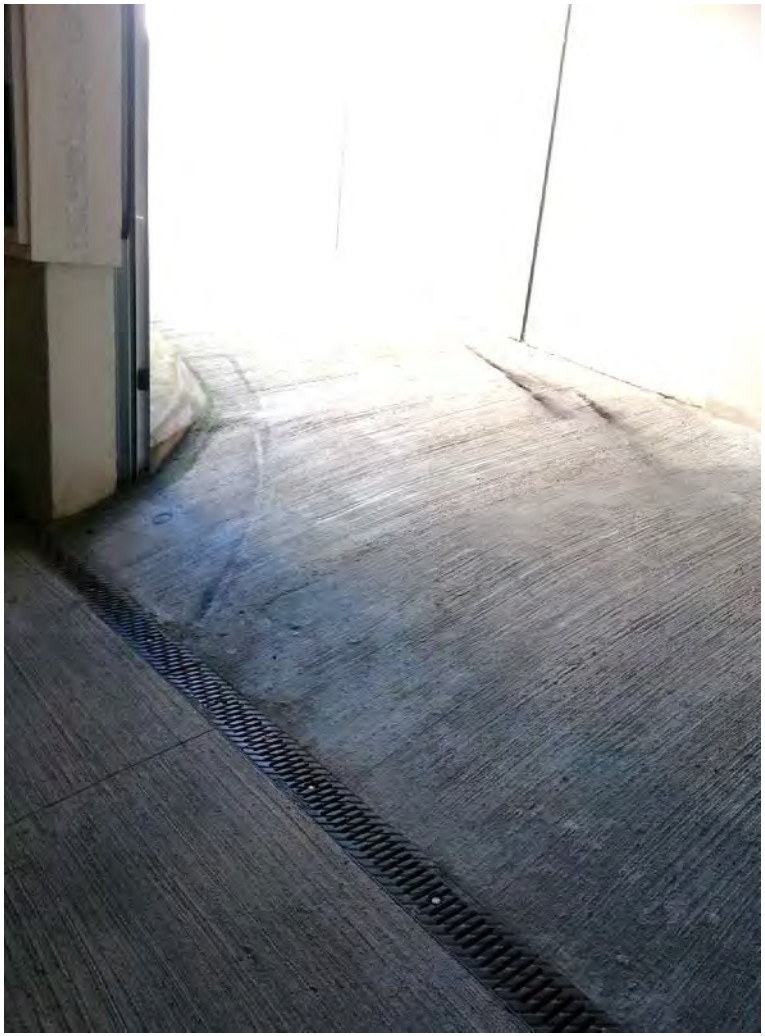
tan <a = h / l
tan 15 = 26,79 / 100 = 0,2679
15° entspricht somit 26,8%

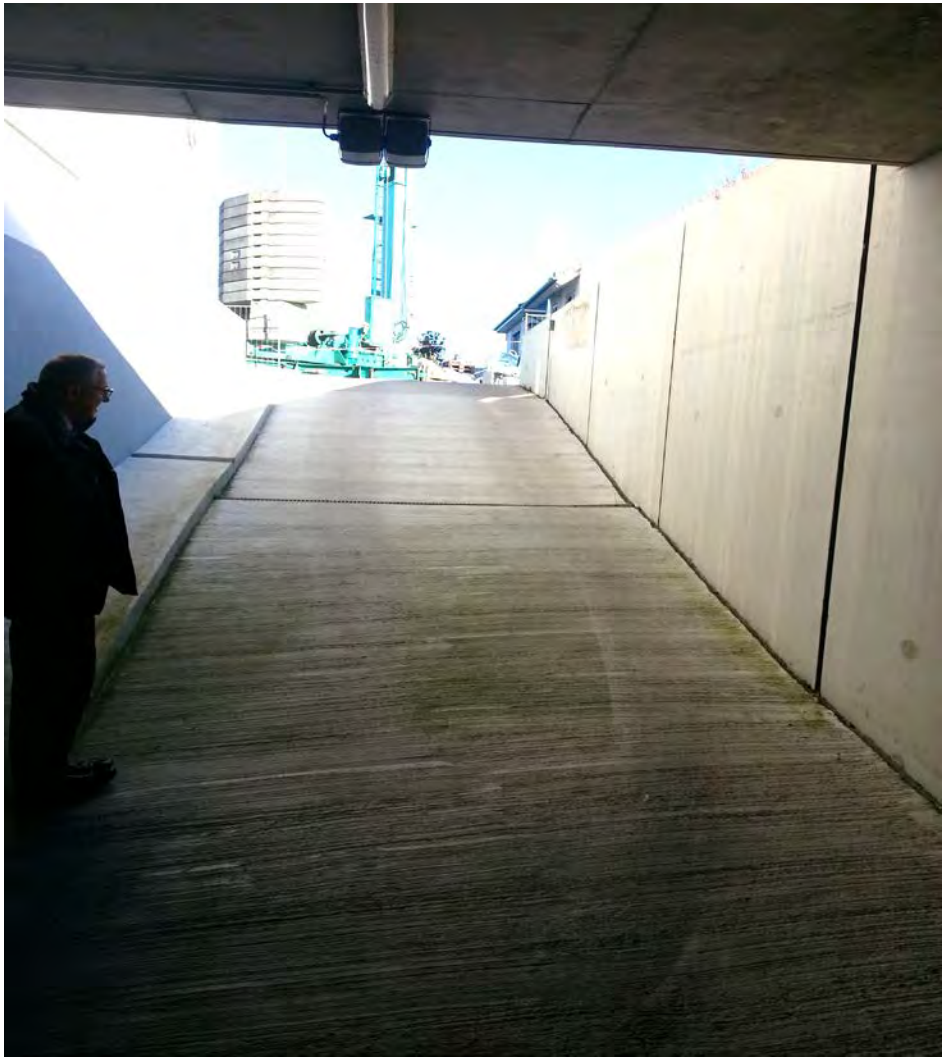
umgekehrt:
15% sind
arct (15/100)= arct 0,15 =
8,53°



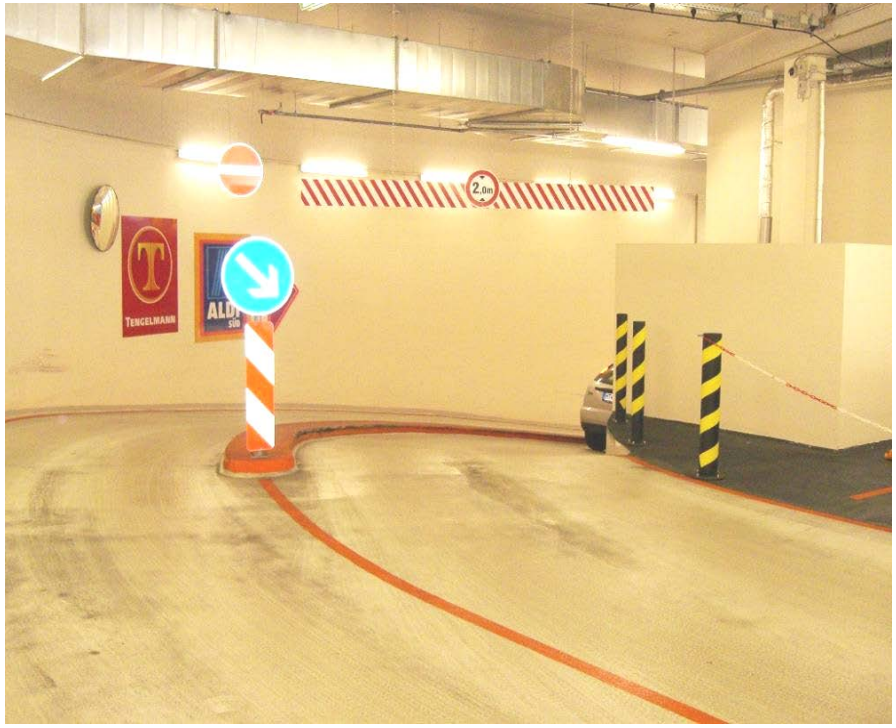


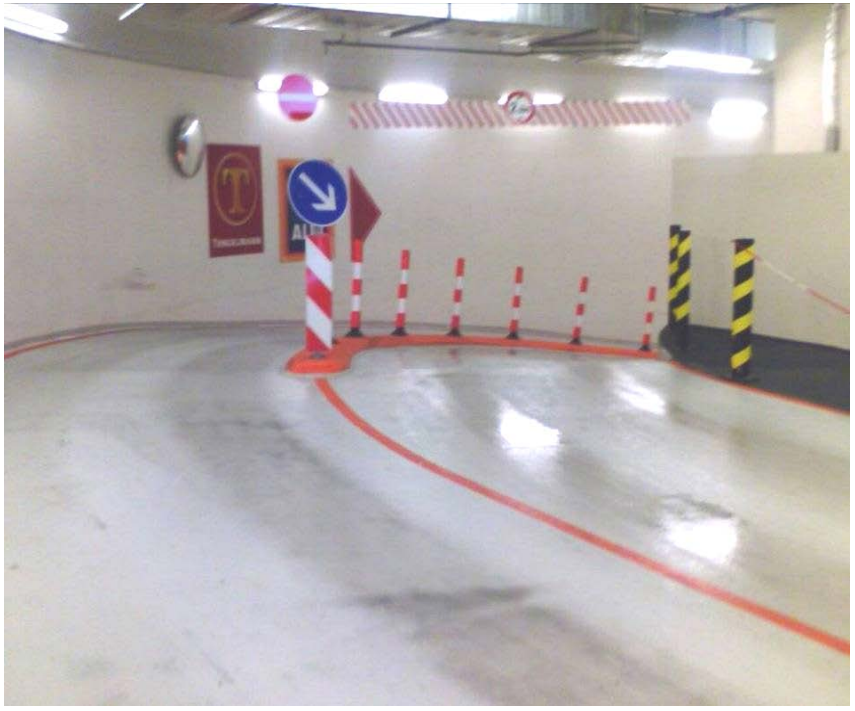
Ramps: Bad example short ramp (again built ~15° instead of 15%!)





Ramps: Difficult: curve to the right





Source 8

- **Content**
  1. **Introduction**
  2. **Design vehicle**
  3. **Parking lots and lanes**
  4. **Headroom**
  5. **Ramps**
  6. **Queue length**
  7. **Construction of parking facilities**
  8. **Bicycle parking**
  9. **Loading docks**

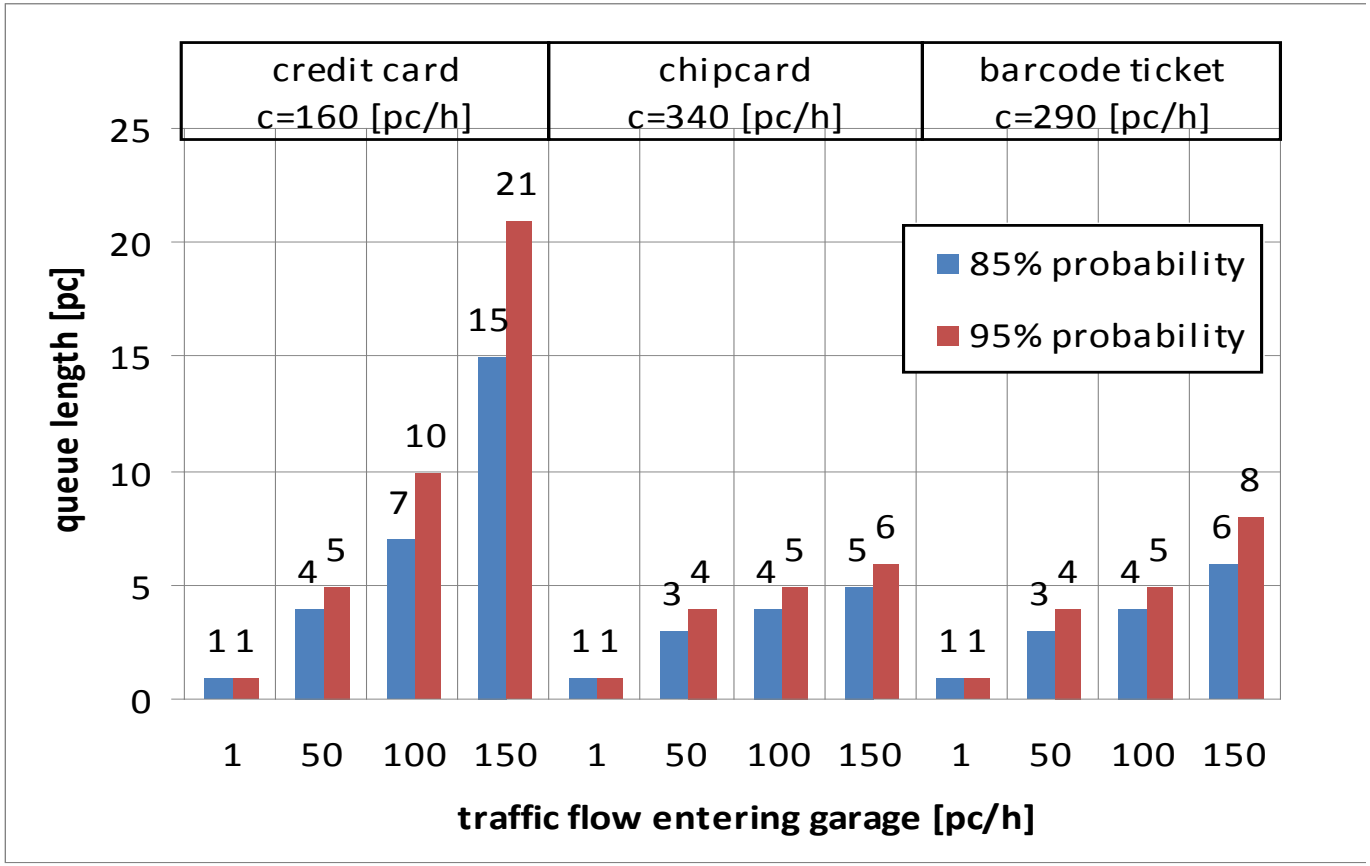
- **Queue length:**

  Entrance and exit barriers can lead to considerable queue lengths

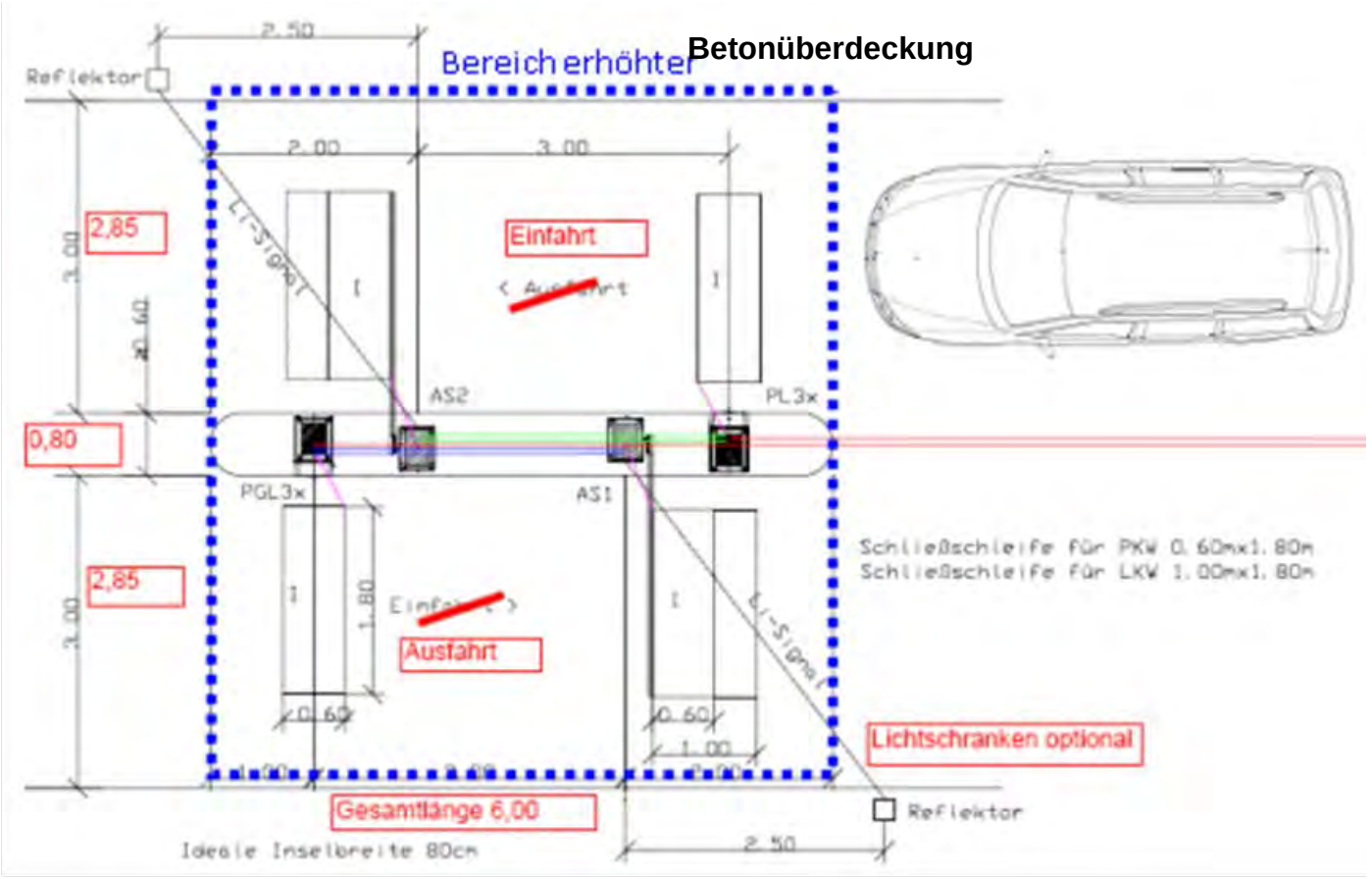
  can disturb through traffic on the adjacent street and/ or the inner garage traffic flow.

  German guidelines for garage facilities introduce a method to assess the queue length based on empirically known capacity of certain control devices

Queue length: Number of waiting cars at a barrier with certain methods of control (derived from EAR 05, Annex K)



Queue length: barriers (source Scheidt&Bachmann)



- **Content**
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- **Construction aspects of parking facilities:**
  1. **Planning:**
     - **Different sections of planning are involved → interfaces need to be covered**
     - **Object planer: Determine the way the parking facility is build → ramps, way the lots are arranged, size of lanes, colors, details etc.**
     - **Constructional planning: Make sure construction is safe → calculate forces having an impact on the parking facility, state needed column grid**
     - **Technical planning: Electricity, sewing, fire prevention etc.**

- **Construction aspects of parking facilities:**

1. **Planning: - horizontal impact (2 kN if dropping possible, otherwise 1 kN):**

- **Construction aspects of parking facilities:**
  2. **Fire prevention:**
     - **Load bearing elements have to be build out of non flammable material**
     - **Underground, self contained and in buildings integrated parking facilities have to have a fire resisting of REI 90**
     - **Open garages and above ground garages in general only need a fire resistance of REI 30**
     - **Fire protection gate:**

Source 8

- **Construction aspects of parking facilities:**
  2. **Fire prevention:**
     - **Laws differ from country to country**
     - **If smoke can not exhaust naturally during a fire, a mechanical ventilation system has to be installed to thin the smoke**
     - **Fire detectors and sprinklers have to be installed; in big facilities fire detectors automatically need to alarm the fire department**
     - **Enough fire extinguishers have to be available; wall hydrants have to be abound**

- **Construction aspects of parking facilities:**
  3. **Surface:**
     - **Garages are usually not heated → all surfaces have to be frost-resistant and let water drain off**
     - **Walls and columns should be painted CO-resistant, 50 cm on the bottom should be painted dark so carbon stains do not show**
     - **Pavement has to be abrasion resistant, cleanable, able to hold colors and cover cracks, which can occure in the concrete underneath**
     - **Marking is important for orientation, has to be longlasting, easy to clean and understandable**
     - **Surface cover depends on kind of concrete and/ or steel construction**

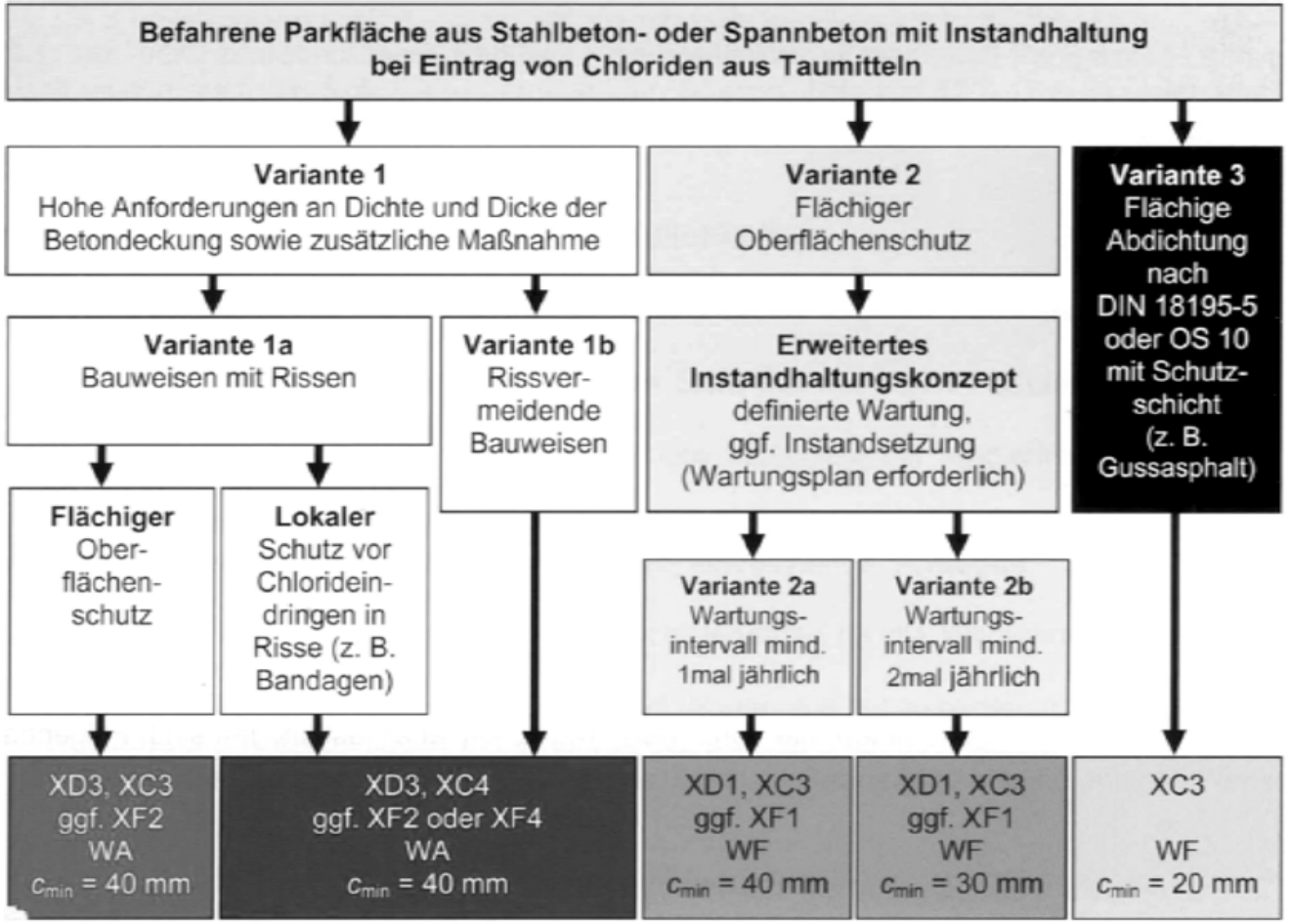
Construction aspects of parking facilities:

4. Concrete:
   - Exposition class XD3 → 3 ways to build
   - Most common: Exposition class XC3 with permanent, crack covering sealing against non pressing water with high capacity of stress resistance composed to the concrete underneath → bitumen sheeting
   - Classification XF required, if frost occurs often

→ For details (e.g. D) see source 12, excerpt next p.

Construction aspects of parking facilities:

4. Concrete: surface recommendations (source 12)



- **Construction aspects of parking facilities:**
  5. **Ventilation:**
     - **Natural ventilation: in small facilities and open garages, if enrichment of the air with health dangering substances is impossible, air flow is warranted**
     - **Mechanical ventilation: Air has to contain less than 100 ppm CO in half an hour, differs in every country, at least 2 equal sized vents with different power supplies, 1 has to be able to fulfill the need of air, if only one is running, the other has to turn itself on automatically if the other shuts down**

Construction of parking facilities:

5. Ventilation:

1. CO-Warning-System has to be installed with it's own power supply, has to go off if CO content is too high

Ventilation pipe:

Source 8

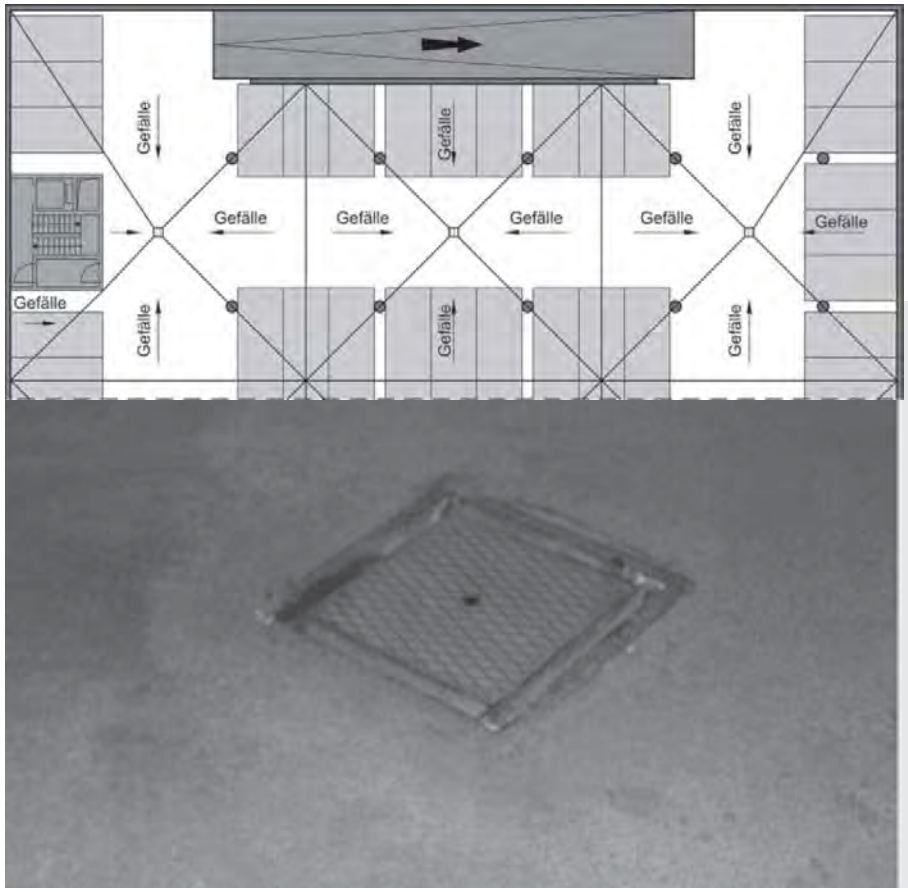
jet ventilator:

- **Construction of parking facilities:**
  6. **Electricity:**
     - **All accessible areas have to be lighted with at least 50 lux**
     - **Emergency lights have to be installed; lighting ways with 0,5 - 5 lux to make sure all emergency exits are reachable without injuries; duration 0,5 – 1 h turning itself on automatically if main light fails**
     - **Approximatly 1 plug in per 1000 m² for cleaning etc.**
     - **Emergency power needed for: emergency light, CO-warning system, fire alarm, sprinkler system, automatic gates and other security systems**
     - **Power supply for electric cars**

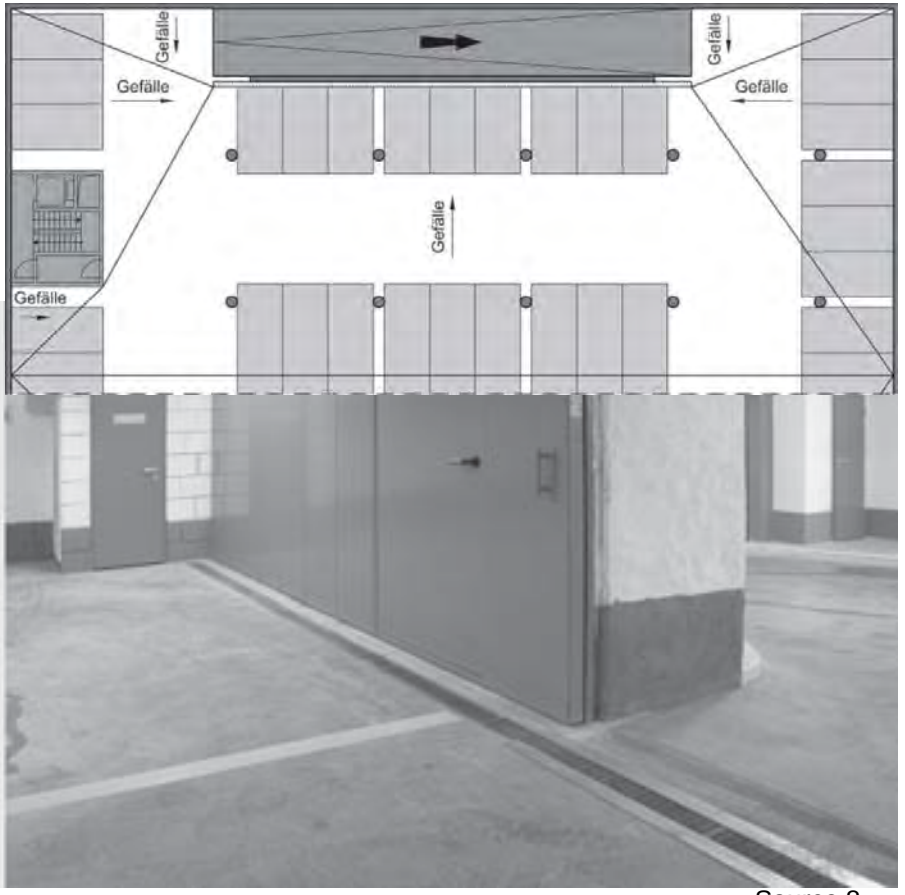
- **Construction of parking facilities:**
  7. **Draining:**
     - **Parking facilities have to be drained like flat roofs to avoid puddle building**
     - **Water can be drained either in gutter or sewers**
     - **If no slope (most common!): client has to accept puddles; construction eng. has to guarantee sustainability; gutters (middle of the driveway) for cleaning water; facility management timetable!**

- **Construction aspects of parking facilities: Drainage**

Sewer:



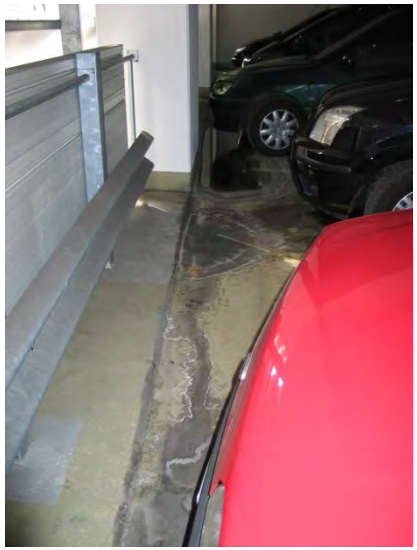
Gutter:



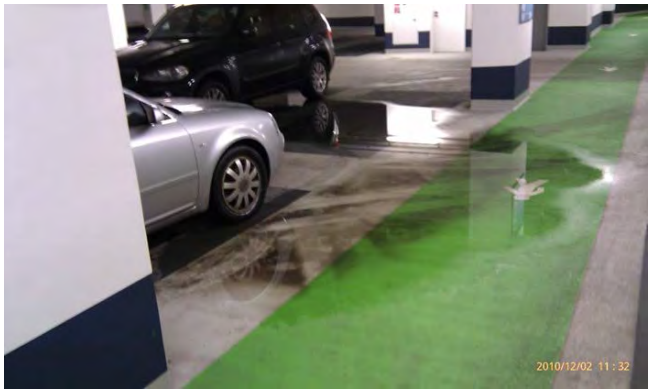
Source 8

Construction aspects of parking facilities:

7. Draining: if not done well!



Source : Prof. Schäper, HSRM



- **Content**
  1. Introduction
  2. Design vehicle
  3. Parking lots and lanes
  4. Headroom
  5. Ramps
  6. Queue length
  7. Construction of parking facilities
  8. Bicycle parking
  9. Loading docks

Bicycle parking: Number of bike-lots depends on user profile and modal split

Example: Frankfurt city regulation 2017

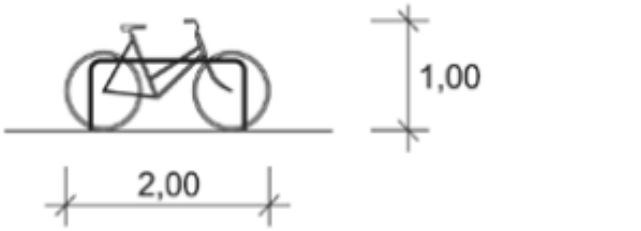
Anlage 1 - Stellplatzzahlen

	Verkehrsquelle	Zahl der Stellplätze für Kraftfahrzeuge	Zahl der Abstellplätze für Fahrräder
1	**Wohnungen**		
1.1	Ein- und Zweifamilienhäuser	1,5 je Wohneinheit (WE)	3 je WE
1.2	Mehrfamilienhäuser (ab 3 WE)	Außerhalb der Zonen I bis IV: 1,1 je 100 qm BGF Zone I : 1,0 je 100 qm BGF Zone II : 0,8 je 100 qm BGF Zone III : 0,8 je 100 qm BGF Zone IV : kein Stellplatzbedarf	1 je 40 qm BGF
1.3	Kinder- und Jugendwohnheime	1 je 20 Betten, mindestens 2	1 je 2 Betten
1.4	Wohnheime	1 je 3 Betten, mindestens 2	1 je 2 Betten
1.5	Altenwohnheime	1 je 10 Betten, mindestens 2	1 je 10 Betten
2	**Büro- und Verwaltungsräume, Räume für freie Berufe**		
2.1	Büro-, Verwaltungsräume, Praxen freier Berufe	1 je 50 qm BGF	1 je 125 qm BGF mindestens 3 je Einheit

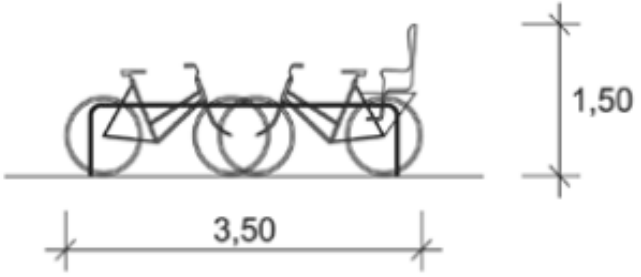
… more

Bikes at highriser F: 07:30 and 09:30

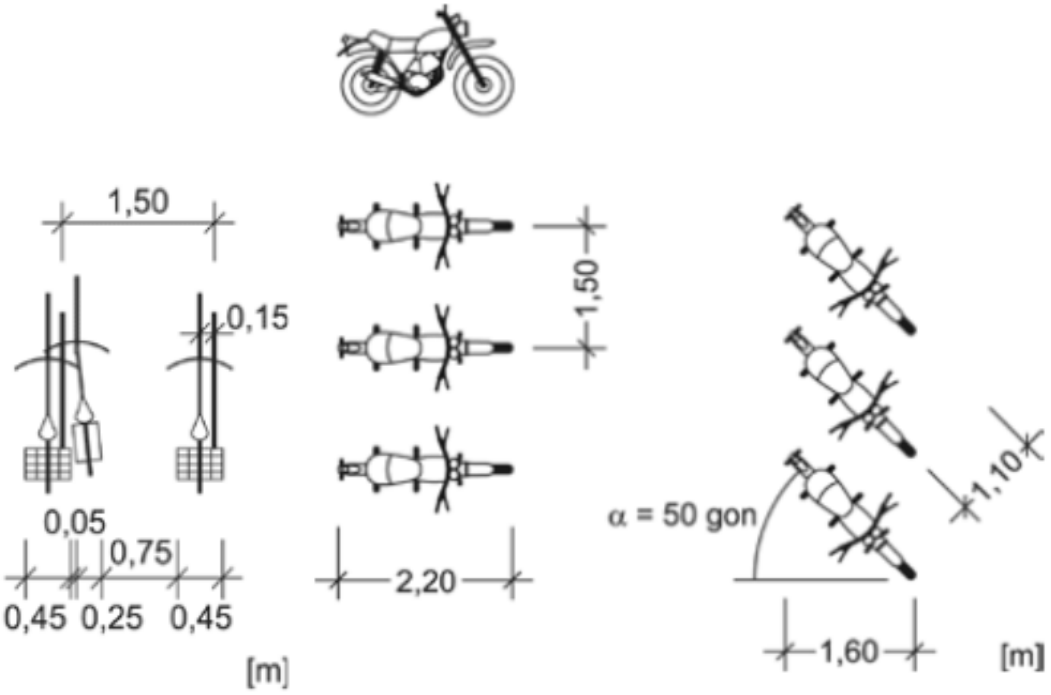
Bike parking (source 1):



höhengleiche Einzelaufstellung

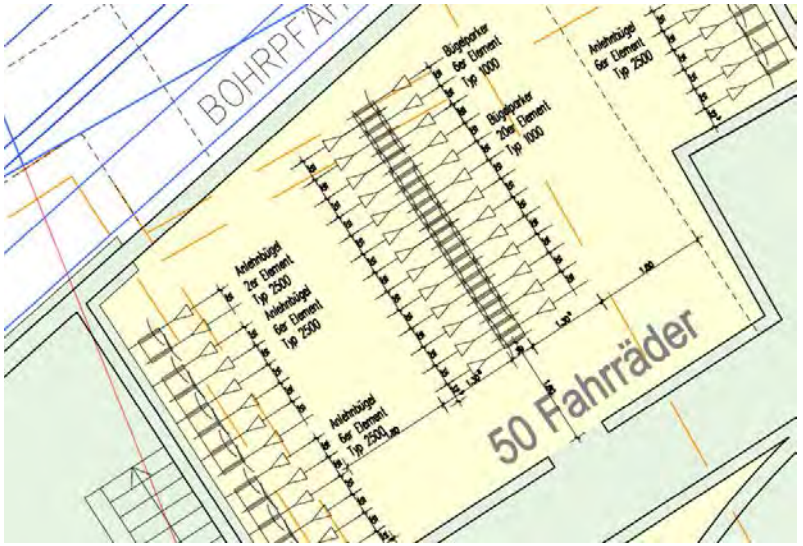


höhengleiche Doppelaufstellung
mit Vorderradüberlappung



Achsabstand bei
Rahmenhaltern

Bicycle parking (source 1):



Bike parking in an underground garage (very packed!)

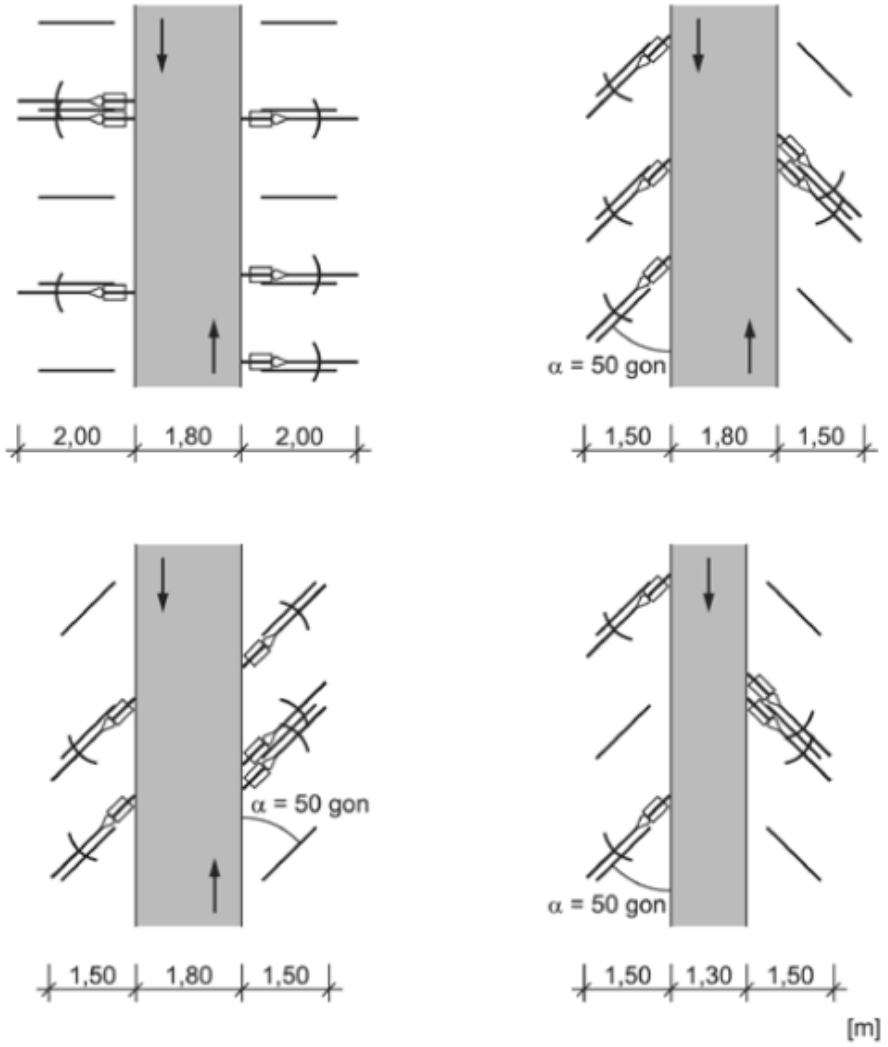


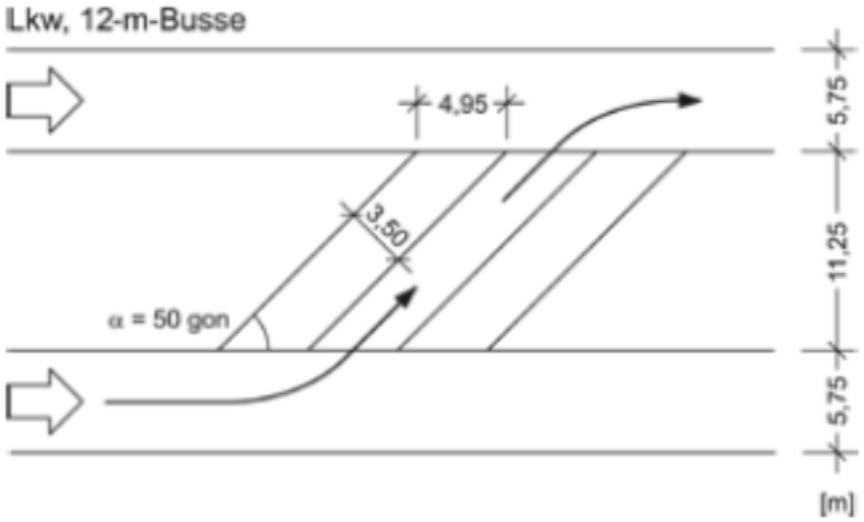
Bild 4.2-10: Parkstandabmessungen und Fahrgassenbreiten in Fahrradabstellanlagen

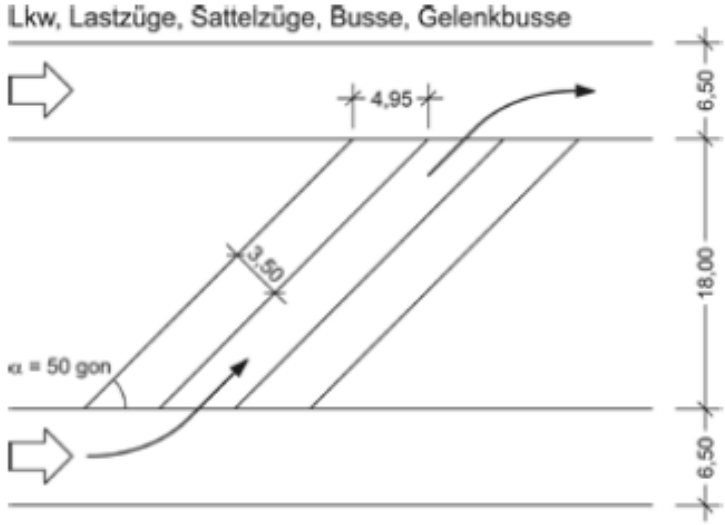
- **Content**
  1. **Introduction**
  2. **Design vehicle**
  3. **Parking lots and lanes**
  4. **Headroom**
  5. **Ramps**
  6. **Queue length**
  7. **Construction of parking facilities**
  8. **Bicycle parking**
  9. **Loading dock and truck parking**

Truck parking (source 1):

Tabelle 4.2-2: Fahrgassenbreiten bei der Senkrechtaufstellung von Reisebussen

	Überstreichen von Flächen im Seitenraum möglich		Überstreichen von Flächen im Seitenraum nicht möglich	
	Einfahrgasse [m]	Ausfahrgasse [m]	Einfahrgasse [m]	Ausfahrgasse [m]
12-m-Bus	8,30	8,30	12,30	10,00
15-m-Bus	13,00	8,50	20,20	13,00





Loading dock (source 1):

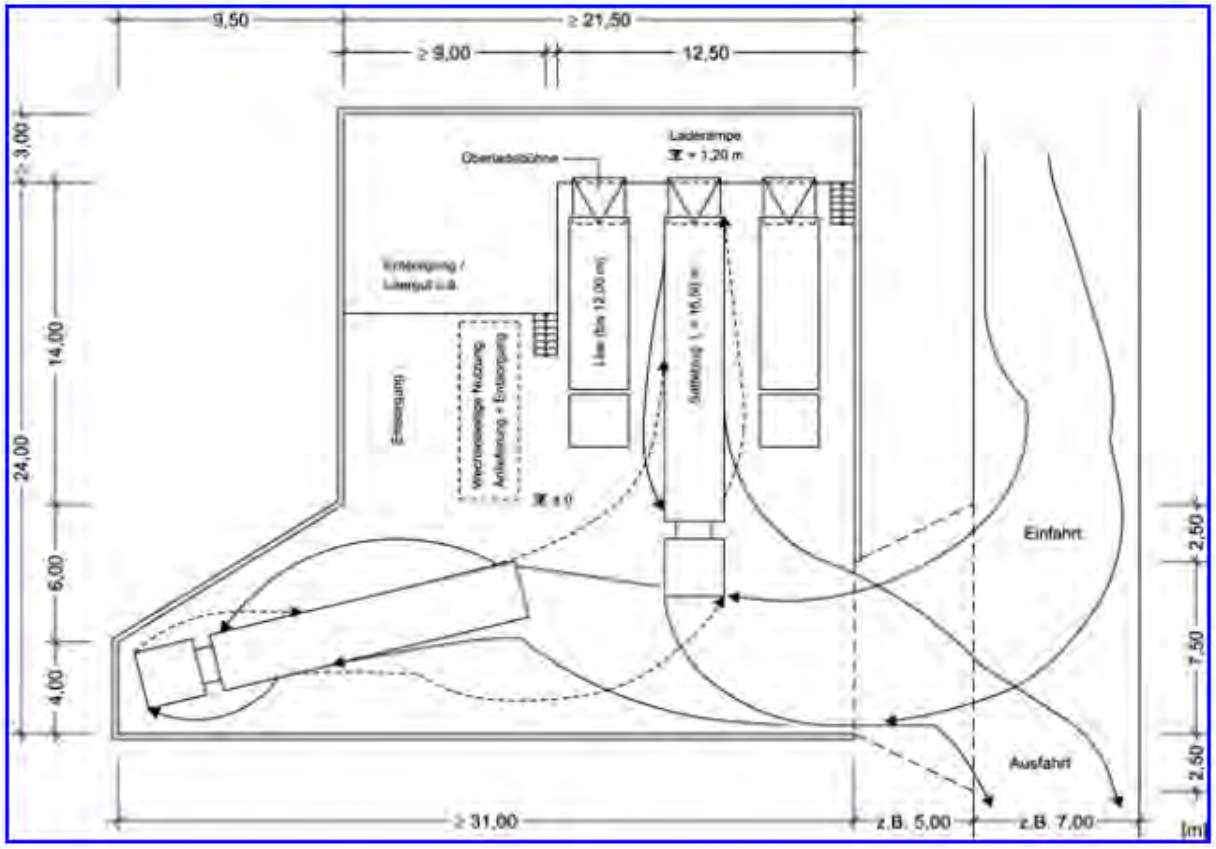


Bild 4.6-1: Beispiel für einen offenen Ladehof eines Warenhauses mit seitlicher Ein- und Ausfahrt

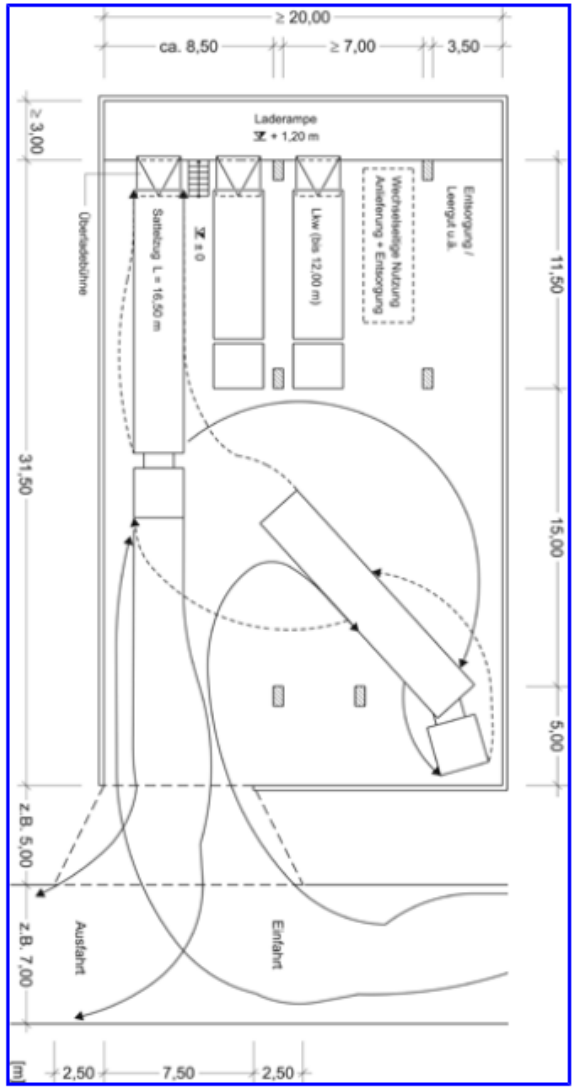
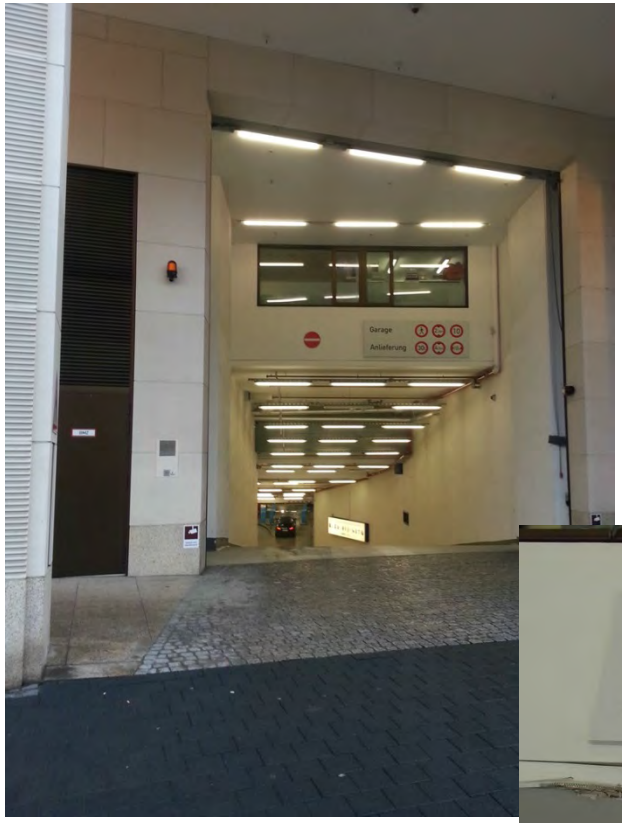
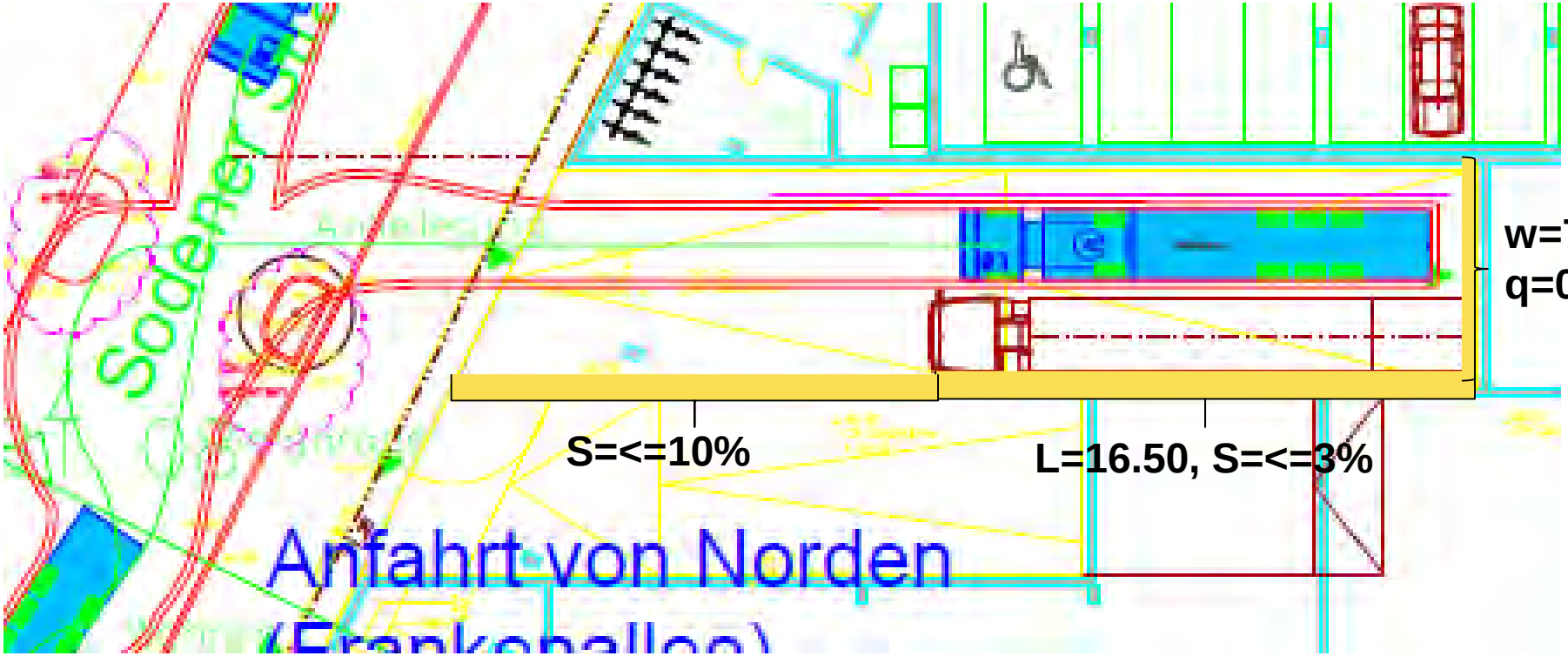


Bild 4.6-2: Beispiel für einen überbauten Ladehof eines Warenhauses mit Ein- und Ausfahrt in Längsrichtung

Loading dock (Operntum Frankfurt):



Loading dock (store):



Example: maneuvering truck MLS330

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Hvala na pozornost!

Thank you for your attention!

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