Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
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Department of the Environment, Transport, Energy and Communications DETEC

**Federal Roads Office FEDRO**

# Current approach to the evaluation of the structural safety of bridges in the Swiss motorway network

**International Bridge Forum, Cambridge, 13-16 September 2009**

**Stefan Kun, Senior Structural Engineer**
**Swiss Federal Roads Office**

I361-1285

# Structure of the presentation

1. Introduction – the new FEDRO

1. Civil engineering structures on the motorways in Switzerland
   - Inventory of bridges
   - Overview of applied design codes

1. Management by FEDRO of the structural safety of existing bridges
   - Updating of traffic loads
   - Evolution of design codes
   - Case study – Aabachweiher bridge

1. Conclusions

# Duties of the Swiss Federal Roads Office

- The Swiss Federal Roads Office (FEDRO) is the Swiss authority that is responsible for the country's road infrastructure and private road transport. It belongs to the Federal Department of the Environment, Transport, Energy and Communications (DETEC).

- As of 1 January 2008, its range of duties increased significantly. With the entry into effect of the redistribution of financial responsibility and the accompanying division of duties between the federal government and the cantons, it assumed the functions of developer and operator of the motorway network.

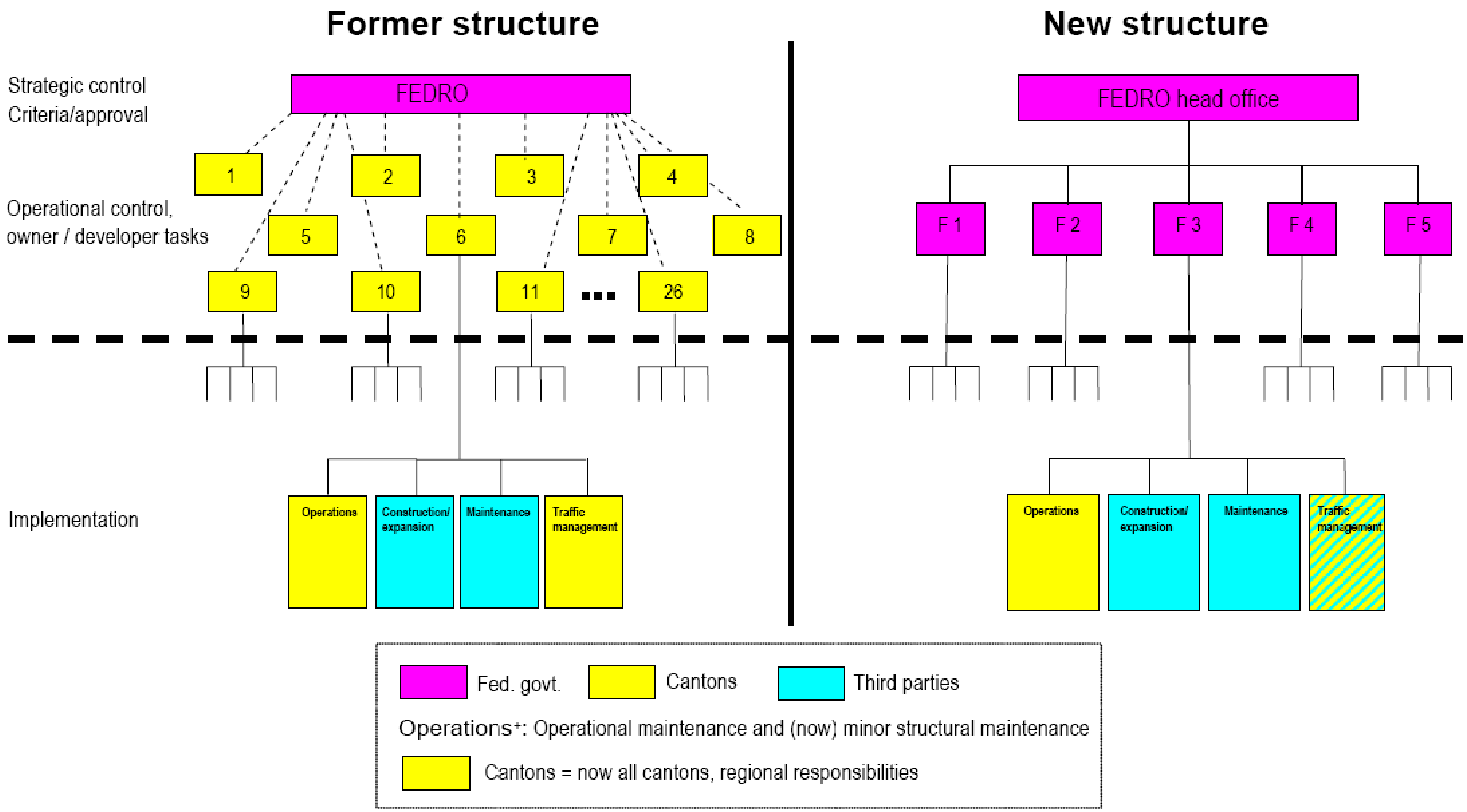
# Distribution of duties between the federal government and the cantons

| Financing system for motorways and traffic management | | | | |
|---|---|---|---|---|
| | Former system | | New system - 01.01.2008 | |
| | Strategic | Operational | Strategic | Operational |
| Construction / improvement<br>• New stretches: completion of network (according to present plans) | Federal government | Cantons | Federal government | Cantons |
| • Additional stretches / expansion (according to future plans) | Federal government | Cantons | Federal government | Federal government |
| • Motorway improvement | Federal government | Cantons | Federal government | Federal government |
| Maintenance | Federal government | Cantons | Federal government | Federal government |
| Operation, including non-project-based current maintenance | Federal government | Cantons | Federal government | Cantons |
| Traffic management on motorways | Federal government | Cantons | Federal government | TM-CH (Federal government) / Cantons |

Federal government

Cantons

# Re-organisation of the Federal Roads Office – comparison between old and new structure



# Swiss Federal Roads Office: organisational chart

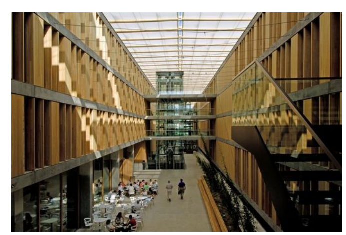
- **Federal Roads Office** (436) – R. Dieterle, Director
  - Quality Management – M. Küpfer (5)
  - Human Resources (+ 6 apprentices) – B. Streit (12)
  - Executive assistant – S. Meister
  - FISP / Auditing – C. Page (8)

- **Political & Official Affairs division** (54) – W. Burgunder, Ass. Dir.
  - Political, economic and international affairs – R. Galliker
  - Legal services & land acquisition – C. Julmy
  - Information and communication – M. Müller
  - Finance and controlling – R. Reist
  - Information technology – D. Landolt
  - Services – P. Lehmann
  - Language services – M. Iff

- **Road Networks division** (51) – E. Wieland, Dep. Dir.
  - MISTRA & Traffic monitoring – C. Käser
  - Network planning – J.-L. Poffet
  - Human-powered mobility – G. Witzig
  - Standards, research, safety – A. Jeanneret
  - Traffic management – H. Suter
  - Traffic management centre CH – M. Wijnhoff

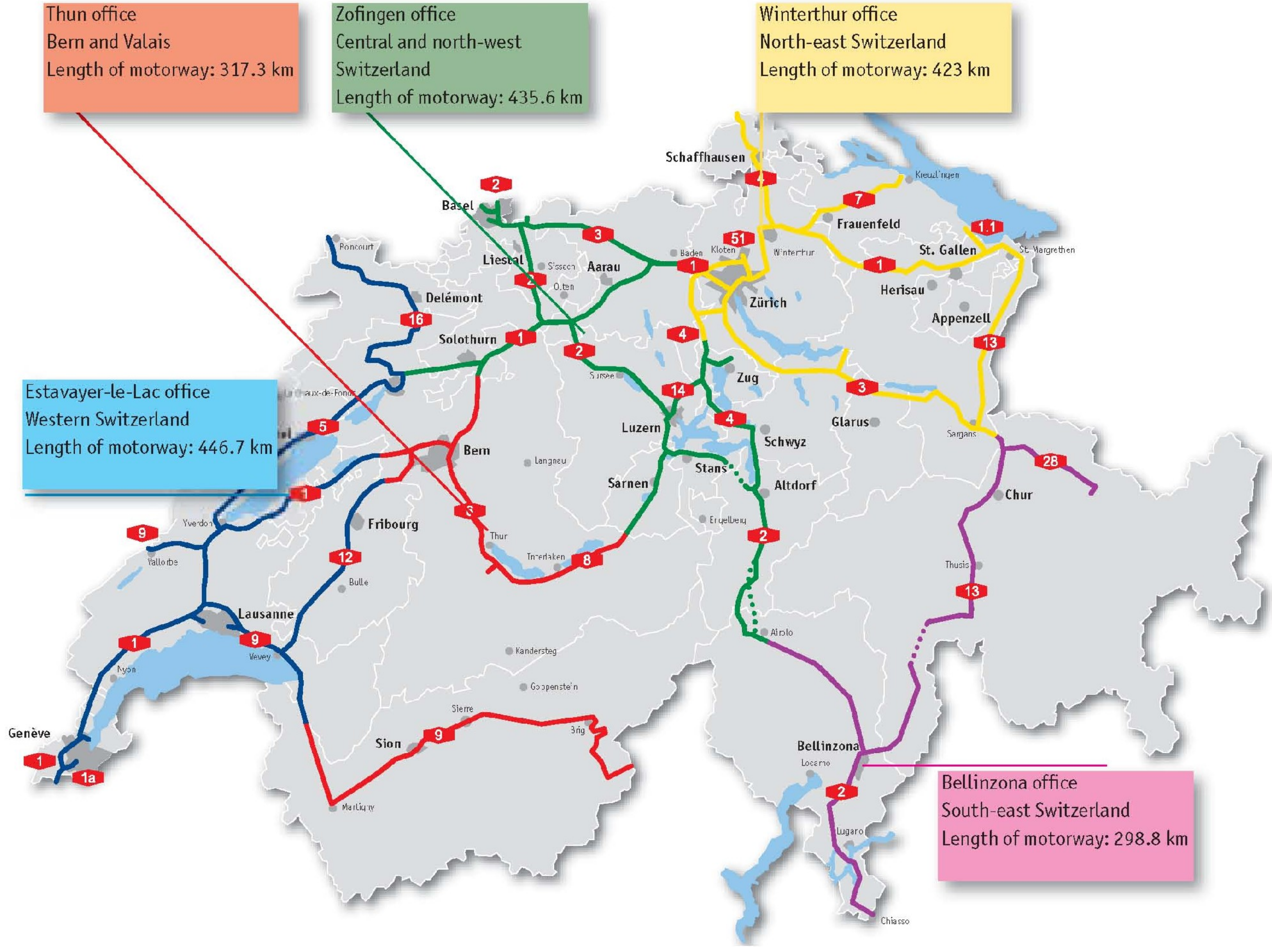
- **Infrastructure division** (229) – J. Röthlisberger, Dep. Dir.
  - Development / Stab – M. Huber
  - Operations – A. Gillardin
  - Investment controlling – J.-B. Duchoud
  - Completion of network – A. Testuz
  - Technical support – J. Berger
  - Estavayer-le-Lac office – P. Schneider
  - Thun office – D. Wetter
  - Zofingen office – T. Weber
  - Winterthur office – O. Noger
  - Bellinzona office – M. Fioroni

- **Road Traffic division** (75) – W. Jeger, Dep. Dir.
  - Data management – C. Baier
  - Traffic safety – V. Fröse
  - Traffic safety & international affairs – C. Jahn
  - Traffic regulations – S. Huonder
  - Registration, liability, penalties – P. Blanc
  - Driver and vehicle registers – B. Nager
  - Vehicles – T. Gasser
  - Vehicle homologation – S. Wenger



Figures refer to no. of employees
Organisational chart valid from 1.1.2007, last update

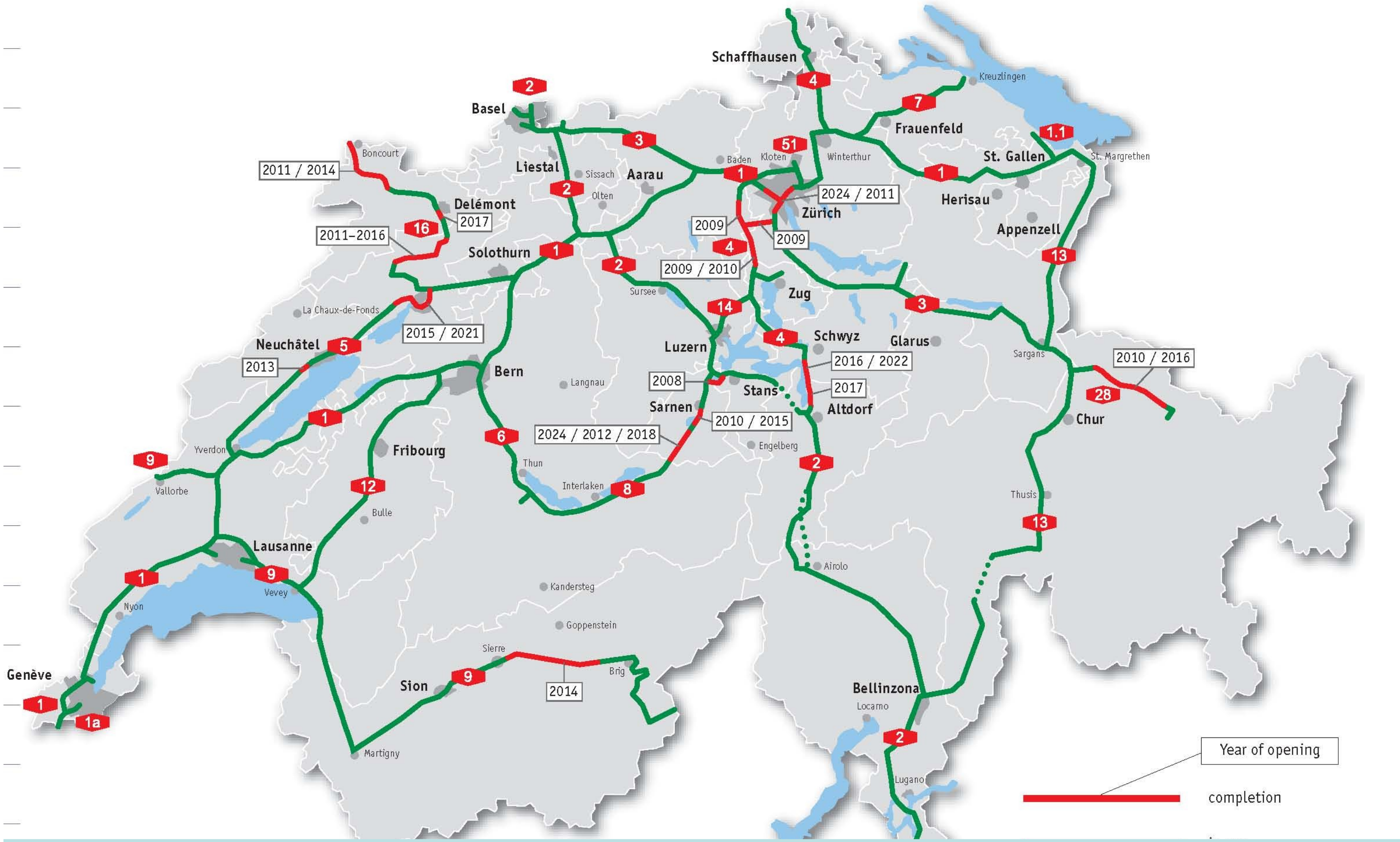
# New FEDRO branch offices and their areas of responsibility



# Investments in 2008 for development and maintenance of the motorway network

- The Swiss Federal Roads Office invested 2.15 billion Swiss francs in the motorway network in 2008.
- The sum of 1.18 billion was allocated for the **expansion and maintenance of the existing network.**
- A further 950 million Swiss francs were drawn from the infrastructure fund to cover the **construction of new stretches.**

# The Swiss motorway network



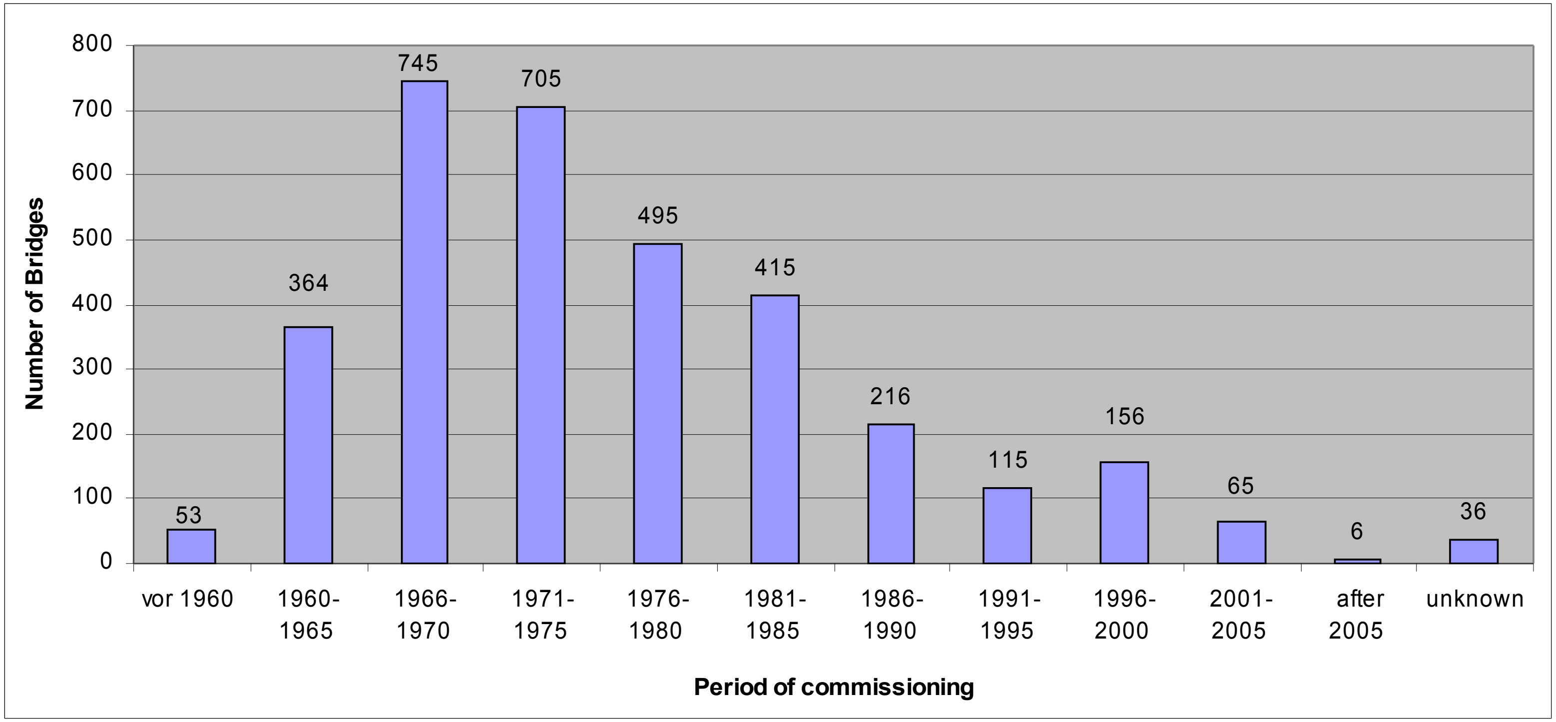

**At present a total of 1,763.6 kilometres of motorway are in operation. According to the existing plans, when it is completed the network will comprise 1,892.5 kilometres. The remaining 129.9 kilometres are expected to be completed within the next 15 years.**

# Inventory of civil engineering structures on Switzerland's motorways - 2007

| Structure type and period of commissioning | Bridges | Galleries | Cut and cover tunnels | Culverts | Retaining structures | Protection galleries | Tunnels | Not classified | Total |
|---|---|---|---|---|---|---|---|---|---|
| Before 1960 | 53 | 1 | 0 | 26 | 16 | 31 | 2 | 0 | 129 |
| 1960-1965 | 364 | 4 | 2 | 81 | 71 | 2 | 7 | 2 | 533 |
| 1966-1970 | 745 | 25 | 14 | 151 | 212 | 19 | 32 | 8 | 1206 |
| 1971-1975 | 705 | 22 | 20 | 134 | 169 | 25 | 6 | 1 | 1082 |
| 1976-1980 | 495 | 12 | 12 | 163 | 101 | 55 | 11 | 2 | 851 |
| 1981-1985 | 415 | 15 | 27 | 79 | 151 | 22 | 26 | 2 | 737 |
| 1986-1990 | 216 | 9 | 21 | 40 | 45 | 45 | 6 | 1 | 383 |
| 1991-1995 | 115 | 9 | 34 | 16 | 16 | 40 | 3 | 1 | 234 |
| 1996-2000 | 156 | 12 | 26 | 42 | 47 | 51 | 7 | 0 | 341 |
| 2001-2005 | 65 | 3 | 33 | 12 | 14 | 25 | 4 | 5 | 161 |
| After 2005 | 6 | 0 | 0 | 3 | 0 | 0 | 0 | 1 | 10 |
| Not known | 36 | 55 | 1 | 4 | 23 | 89 | 101 | 3 | 312 |
| Total | 3,390 | 113 | 193 | 770 | 931 | 416 | 107 | 59 | 5,979 |

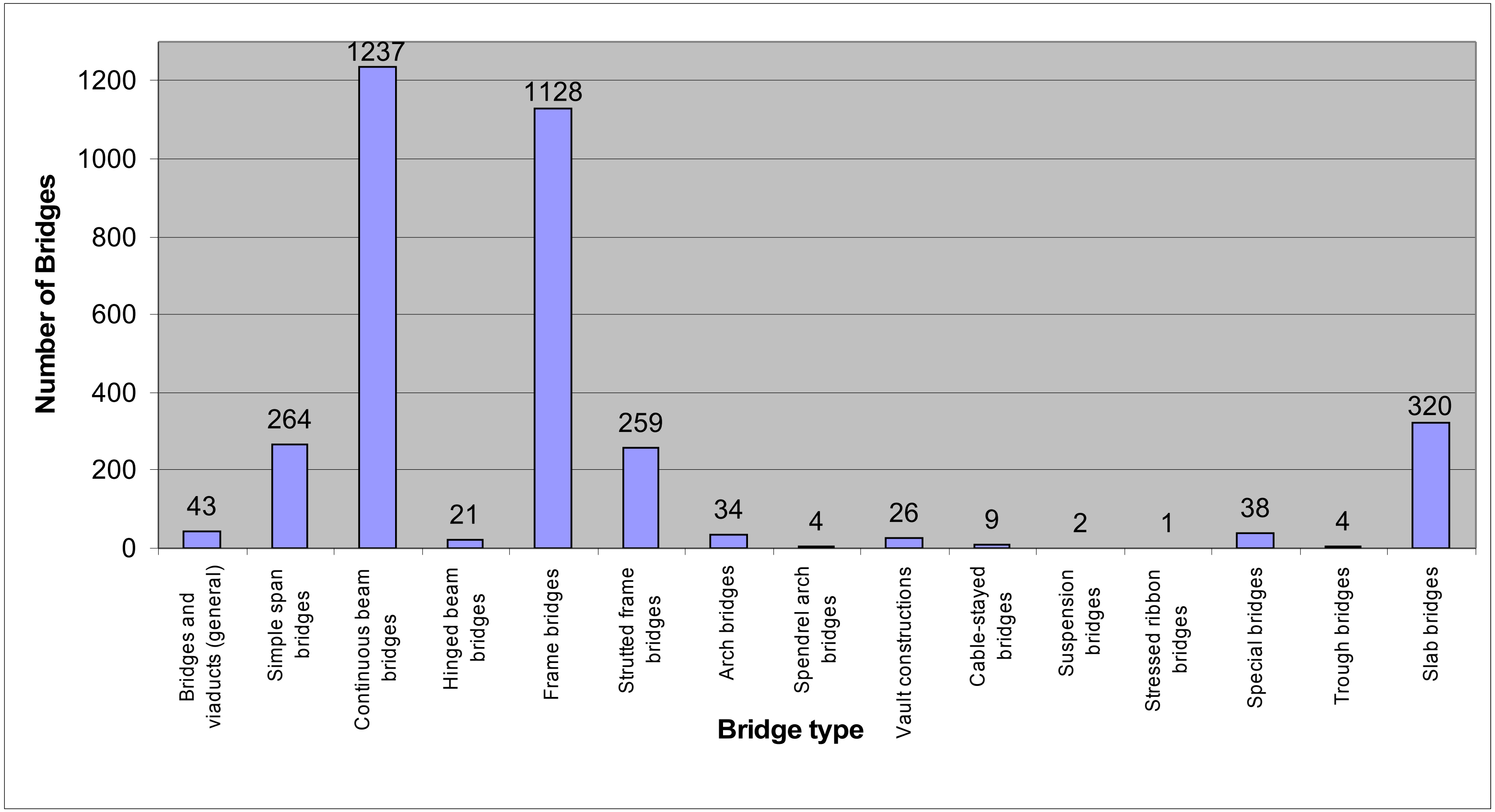
**Bridges account for 56.7% of the total number of civil engineering structures - from AGB Research Report TP 106-2009, and KUBA data base.**

# Number of bridges on the Swiss motorways according to their period of commissioning



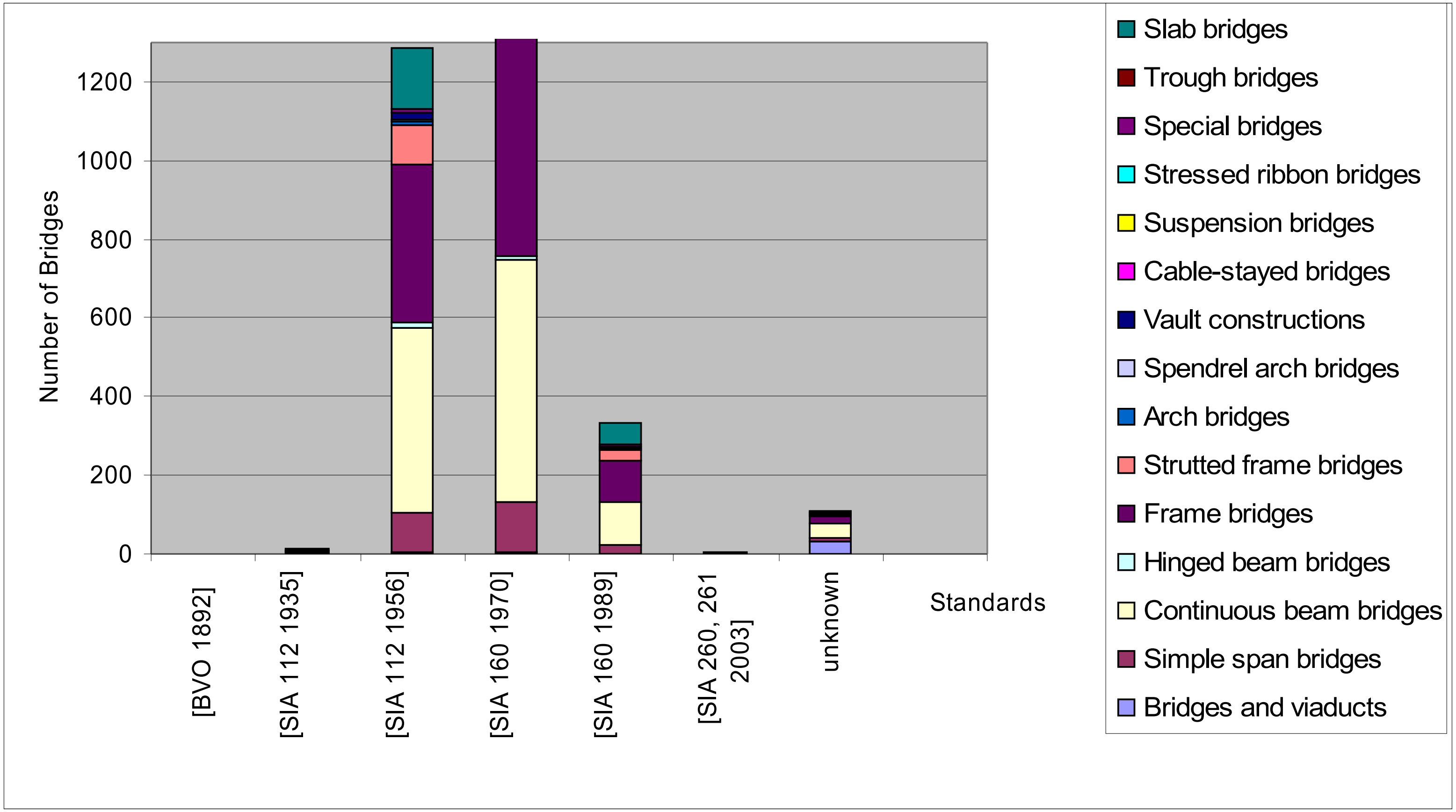

**As the graph shows, the largest number of bridges, were built in the period from 1966 to 1975. These structures are now between 34 and 43 years old.**

# Number of bridges on the Swiss motorways according to their types



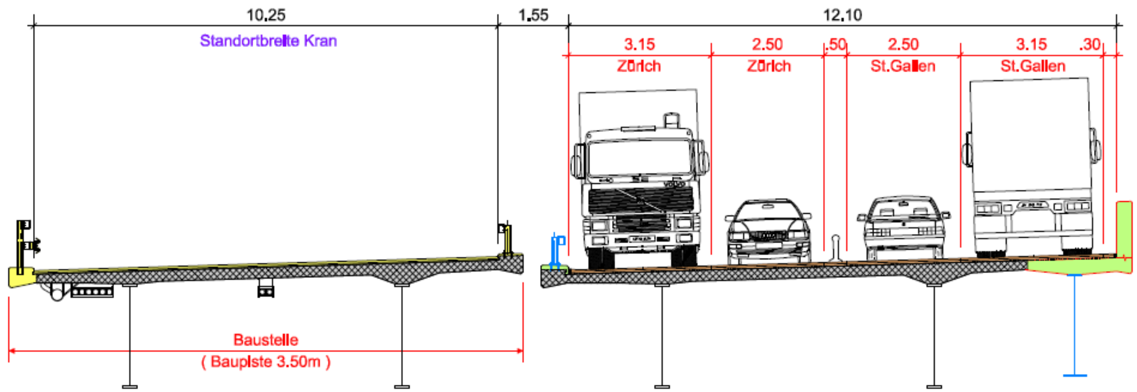

**This graph shows that the most important bridge types on Switzerland's motorways are simple span and continuous beam bridges, integral frame and strutted frame bridges, and slab bridges.**

# Bridges on the Swiss motorways according to their design codes



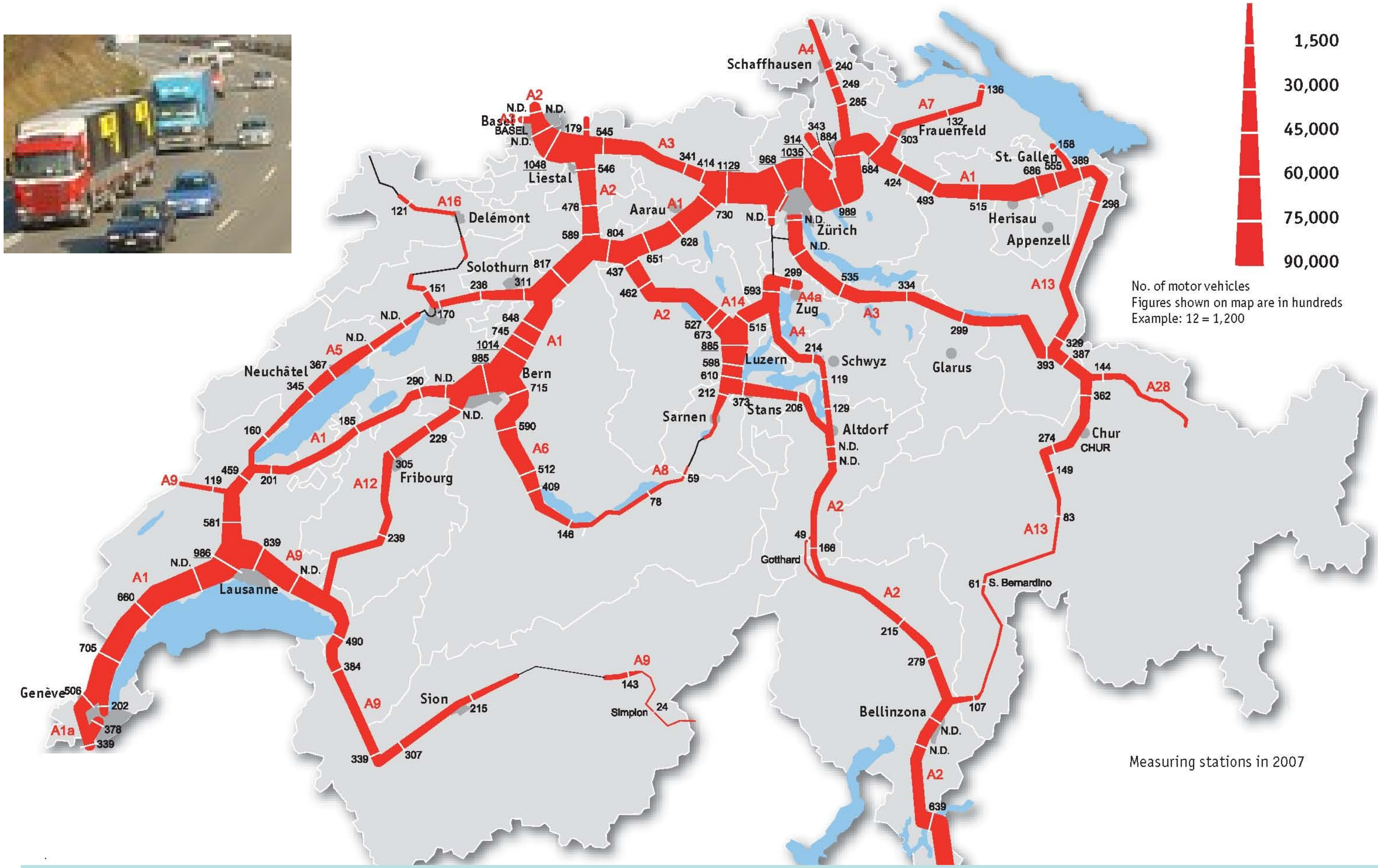

**The majority of bridges were designed and measured in accordance with SIA standards 162 1956 and 162 1970. Source: AGB Research Report TP 106-2009**

# Traffic loads for strength evaluation of existing road bridges



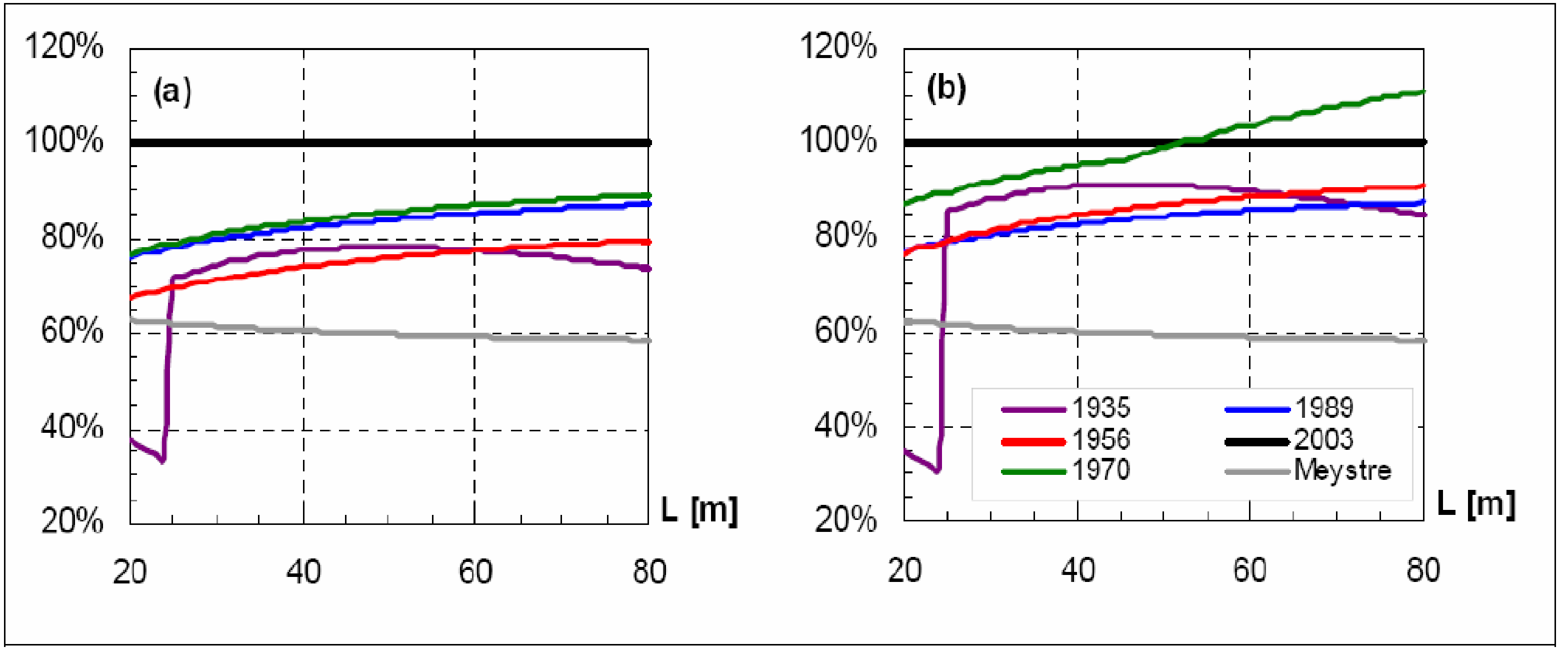

**N1 motorway, canton of Thurgau – Renovation and widening of Lützelmurg viaduct (composite bridge from 1972). The deck slab is to be widened during renovation in order to permit future 4/0 bidirectional traffic (= 2 lanes in each direction). For the evaluation of the structural safety of the old and new structural members, the requirements of the standards were differently taken into consideration.**

# Traffic Volume on the Swiss Motorways in 2007




**In 2007, the average daily traffic volume on Switzerland's motorway network was around 5 million motor vehicles. The network of automatic traffic counting stations covers 163 stretches of motorway**

# Evolution of Swiss SIA standards for traffic loads



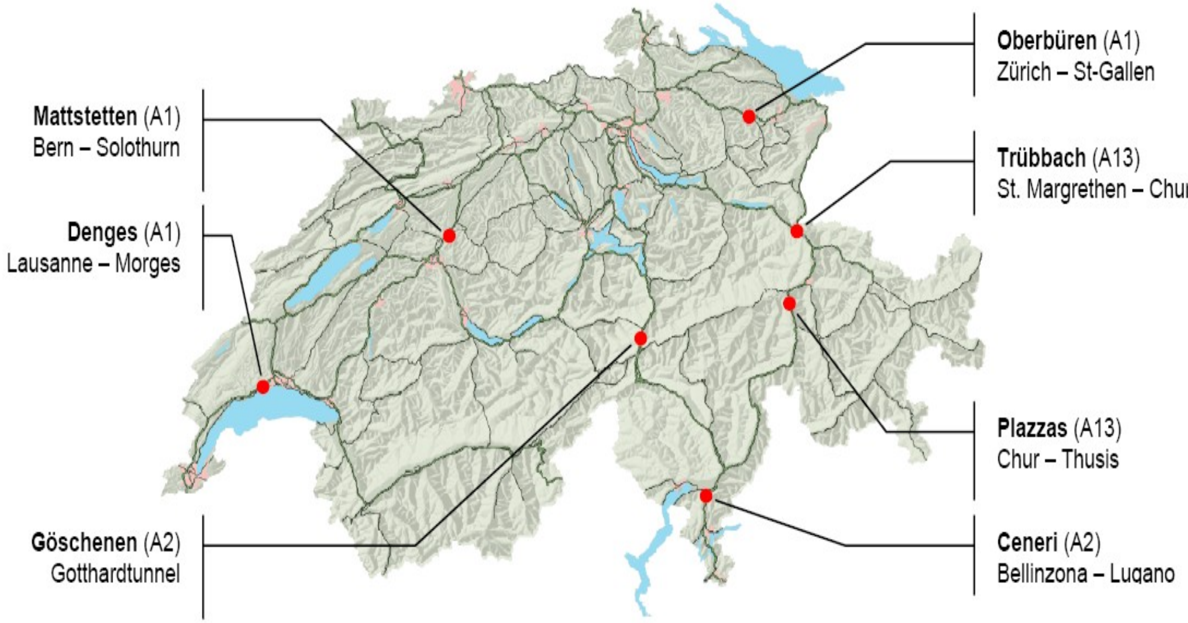

Total vertical traffic loads on characteristic level, based on SIA standard *261 2003*

(a) Bridge deck width 9.0 metres

(b) Bridge deck width 12.0 metres. Source: AGB Research Report TP 107 from 2009.

Here it should be noted that, in comparison with the requirements of present-day standards for traffic loads, the design loads on existing bridges with a deck width of 9 metres are greater (20 to 25%) than on bridges with a deck width of up to 12 metres (10 to 20%).

# Weigh-in-motion (WIM) installations on the Swiss motorway network




- **Road traffic throughout Switzerland is automatically weighed and counted at WIM stations, operated under the management of the Swiss Federal Roads Office (FEDRO).**
- **Data obtained from the 7 WIM stations was used as the basis for traffic simulation purposes at the ICOM – Federal Institute of Technology, Lausanne.**

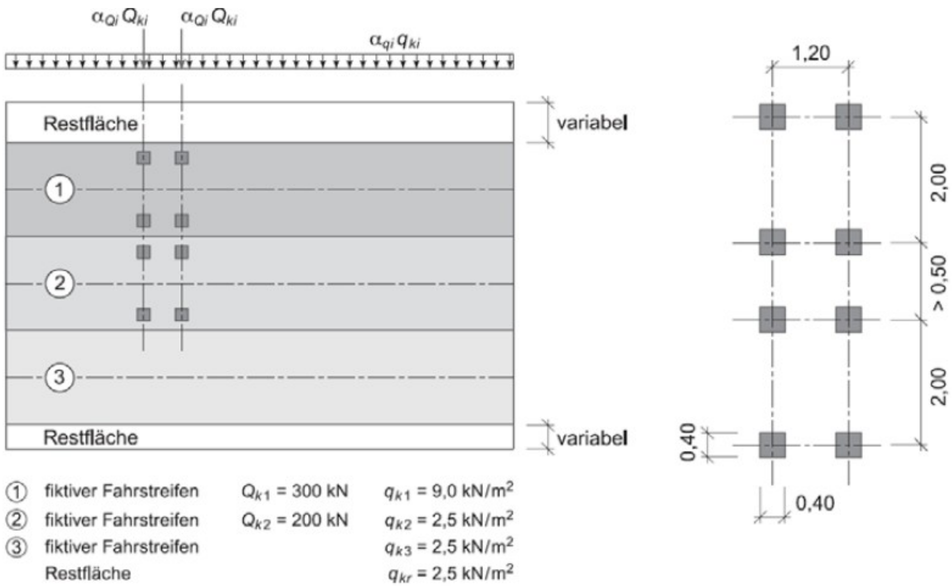
# Updated traffic load model for the evaluation of existing road bridges.

- The “Swiss traffic” load model is limited by a legal truck weight of 40 tons. Trucks heavier than 40 tons need a special license for circulating on the Swiss motorways.

- The model is established to evaluate existing motorway bridges with two lanes and unidirectional traffic with a span width not exceeding 80 m.

- Assumptions were made to for the evolution of the traffic over a time span of 20 years.

- The α coefficients were established at the ICOM – Federal Institute of Technology, Lausanne on the bases of comparisons between the simulated forces and those calculated according to the code. (Research project AGB 2002/005)




| Bridges | Cross Section | Span Length | $\alpha_{Q1}$ | $\alpha_{Q2}$ | $\alpha_{qi}$, $\alpha_{qr}$ |
|---|---|---|---|---|---|
| Beams | Box Girder | 20-80 m | 0.70 | 0.50 | 0.50 |
| | 2 Webs | 20-80 m | | | 0.40 |
| | More Webs | 15-35 m | | | 0.40 |
| Deck Slabs | | 8-30 m | | | 0.40 |

**Updated α coefficients for the application of the SIA 261 load model**

# Prestressed concrete and shear design according to SIA 162 from 1956

- In accordance with the provisions of the code, reinforced concrete members were designed using service loads and permissible service load stresses.
- Shear strength was computed by taking into account the principal stresses in concrete according to the theory of elasticity.
- If the principal slope tensile stresses in homogeneous cross-section did not exceed

**3. Zulässige Spannungen**

Art. 66

In kg/cm²

Beton

| | B. H. | B. S. |
|---|---|---|
| *Zulässige Kantenpressungen:* | 120 | $\beta_d/2{,}5$ $\leqslant 200$ kg/cm² |
| *Zulässige Zugspannungen:* | | |
| 1. Zugspannungen am Rande unter Gebrauchslast: | | |
| Ohne Temperatur . . . . . . . . . . . . | 0 | 0 |
| Mit Temperatur . . . . . . . . . . . . | 10 | $0{,}5 \cdot \sqrt{\beta_d}$ |
| 2. Während der Ausführung dürfen zeitlich begrenzte Zugspannungen zugelassen werden im Betrag von . . . . . . . . . . . . | 20 | $\sqrt{\beta_d}$ |
| *Zulässige schräge Hauptzugspannungen:* | | |
| 1. Im allgemeinen . . . . . . . . . . . . | 8 | $0{,}5 \cdot \sqrt{\beta_d}$ |
| 2. Werden die Werte unter 1. überschritten, so sind sämtliche Zugspannungen durch schlaffe Armierungen gemäss Artikel 34 aufzunehmen. In diesem Falle dürfen die schrägen Hauptzugspannungen folgende Werte nicht überschreiten . . . . . . . . . . . . | 20 | $1{,}2 \cdot \sqrt{\beta_d}$ |

**Source: SIA standard 162 / 1956, page 39**

**Provided shear strength according to the code SIA 162 from 1956 in most cases meet not the requirements of the current code generations based on a conventional truss model with variable angle.**

# Review of different design procedures for shear strength in accordance with SIA codes

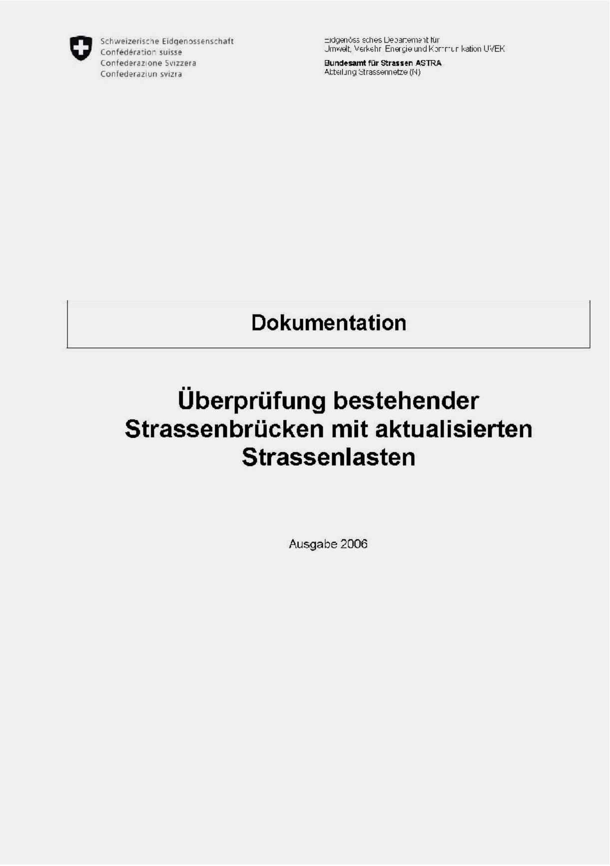
| SIA 162 / 1968 – Guideline 17 | | | | |
|---|---|---|---|---|
| **Ultimate shear force** | **Upper limit of shear stress in concrete** | **Shear resistance of concrete compressive stress zone** | **Additional shear resistance** | **Resistance of shear reinforcement – v. stirrups** |
| $Q^* = s\,(Q_g + Q_p) + Q_v + Q_z$ <br> $(s = s_1 \cdot s_2 = 1{,}8)$ | $\tau^* = \dfrac{Q^*}{b_0 h}$ <br> $\tau^* \leq \tau_2^* = 4\,\tau_1^*$ <br> $\tau_1^* = 8 - 14$ kg/cm$^2$ <br> $\beta_{w28} = 200 - 500$ kg/cm$^2$ | $Q_C^* = \left(1 + \dfrac{V_\infty}{Z_s}\right) \cdot \tau_1^* \cdot b_0 \cdot h$ <br> $Q_C^* = 1{,}5 \cdot \tau_1^* \cdot b_0 \cdot h$ | $Q_N^* = 0{,}2 \cdot \sigma_N \cdot b_0 \cdot h$ | $Q_B^* = \varrho_B \cdot \sigma_{sB} \cdot b_0 \cdot h$ <br> $\varrho_B = \dfrac{F_B}{b_0 \cdot s_B}$ |

- **Ultimate load** : computed with a global factor
- **Prestressed tendons**: $V_\infty$ is the prestressing force after shrinkage and creep of concrete and relaxation of tendons, $Z_s$ is the sum of ultimate yield forces of the reinforcements in the flexural tensile zone
- **Additional shear resistance** : if the ultimate tensile stress do not exceed the value of $\beta_w/20$

| SIA 262 / 2003 | | | |
|---|---|---|---|
| **Dimensioning value of the shear force** | **Resistance of concrete** | **Inclined tendons** | **Resistance of shear reinforcement – v. stirrups** |
| $V_d = V\,\{\gamma_G G_k, \gamma_P P_K, \gamma_{Q1} Q_{k1} \psi_{0i} Q_{ki}, X_d, a_d\}$ | $V_{Rd,c} = b_w\, z\, k_c\, f_{cd} \sin\alpha \cos\alpha$ <br> $25° \leq \alpha \leq 45°$ | $\Delta V_{Rd,p} = P_\infty \sin\beta_p$ | $V_{Rd,s} = \dfrac{A_{sw}}{s} z\, f_{sd} \cot\alpha$ |

- **Design shear force**: calculated with the relevant partial factors corresponding to the load combinations of hazard scenarios
- **Verification of structural safety**: The dimensioning shall generally be carried out on the basis of stress fields ( variable angle truss model)
- **Inclination of the compression field**: may be chosen freely within the following limits: $25° \leq \alpha \leq 45°$. If significant normal force within the web, it is possible to deviate from these limits.
- **Limits for shear strength** : The web dimensions shall be checked for the chosen compression field inclination. In the case of beams with vertical shear reinforcement, the resistance is limited.

# Procedure for strength evaluation of existing concrete structures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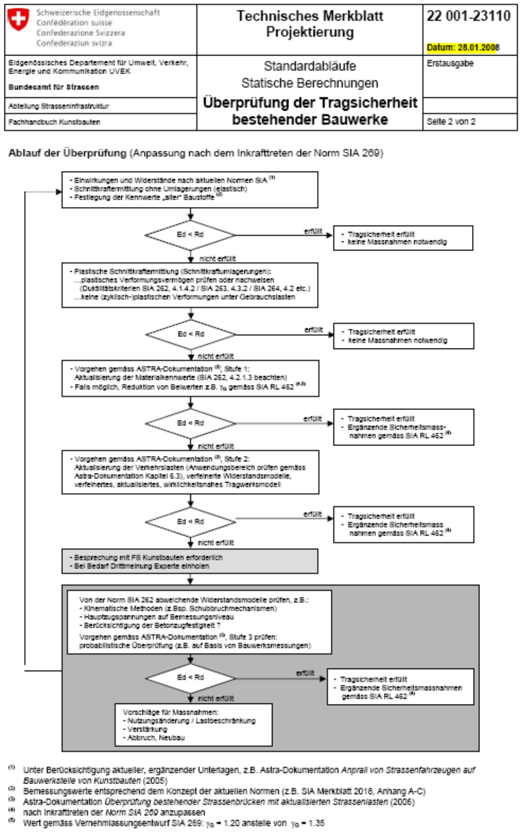
Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK
**Bundesamt für Strassen ASTRA**
Abteilung Strassennetze (N)

**Dokumentation**

**Überprüfung bestehender Strassenbrücken mit aktualisierten Strassenlasten**

Ausgabe 2006



| | | |
|---|---|---|
| Schweizerische Eidgenossenschaft<br>Confédération suisse<br>Confederazione Svizzera<br>Confederaziun svizra | **Technisches Merkblatt<br>Projektierung** | **22 001-23110**<br>**Datum: 28.01.2008** |
| Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation UVEK<br>**Bundesamt für Strassen** | Standardabläufe<br>Statische Berechnungen<br>**Überprüfung der Tragsicherheit bestehender Bauwerke** | Erstausgabe |
| Abteilung Strasseninfrastruktur | | |
| Fachhandbuch Kunstbauten | | Seite 2 von 2 |

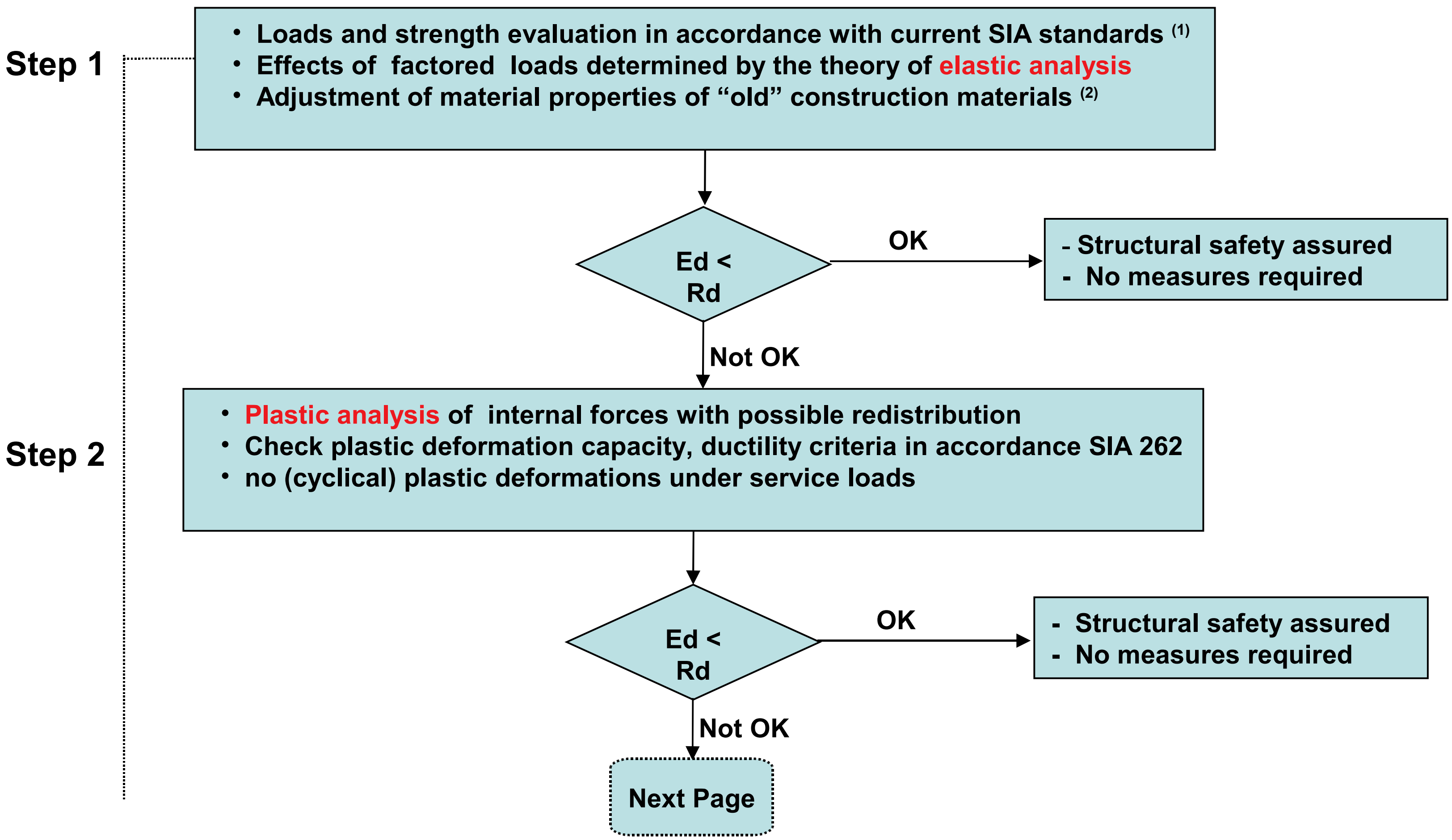
**Ablauf der Überprüfung** (Anpassung nach dem Inkrafttreten der Norm SIA 269)



(1) Unter Berücksichtigung aktueller, ergänzender Unterlagen, z.B. Astra-Dokumentation *Anprall von Strassenfahrzeugen auf Bauwerkstelle von Kunstbauten* (2005)
(2) Bemessungswerte entsprechend dem Konzept der aktuellen Normen (z.B. SIA Merkblatt 2018, Anhang A-C)
(3) Astra-Dokumentation *Überprüfung bestehender Strassenbrücken mit aktualisierten Strassenlasten* (2006)
(4) nach Inkrafttreten der *Norm SIA 269* anzupassen
(5) Wert gemäss Vernehmlassungsentwurf SIA 269: $\gamma_G$ = 1.20 anstelle von $\gamma_G$ = 1.35

**See on the web site FEDRO : www.astra.admin.ch**

# Procedure for strength evaluation of existing concrete structures – Steps 1 to 2



# Procedure for strength evaluation of existing concrete structures – Steps 3-4

**Step 3**

- Procedure in accordance with FEDRO documentation [3], step 1:
- Updating materials properties by investigations and tests – SIA 262
- Reduction of load factors in accordance with SIA RL 462 [4,5]

**Ed < Rd**

OK →
- Structural safety assured
- Additional safety measures in accordance with SIA RL 462 [4]

Not OK ↓

**Step 4**

- Procedure in accordance with FEDRO documentation [3], stage 2:
- Updating traffic loads – α coefficients
- Refined strength models for materials
- Realistic structural analysis model including the real structural behavior

**Ed < Rd**

OK →
- Structural safety assured
- Additional measures in accordance with SIA RL 462 [4]

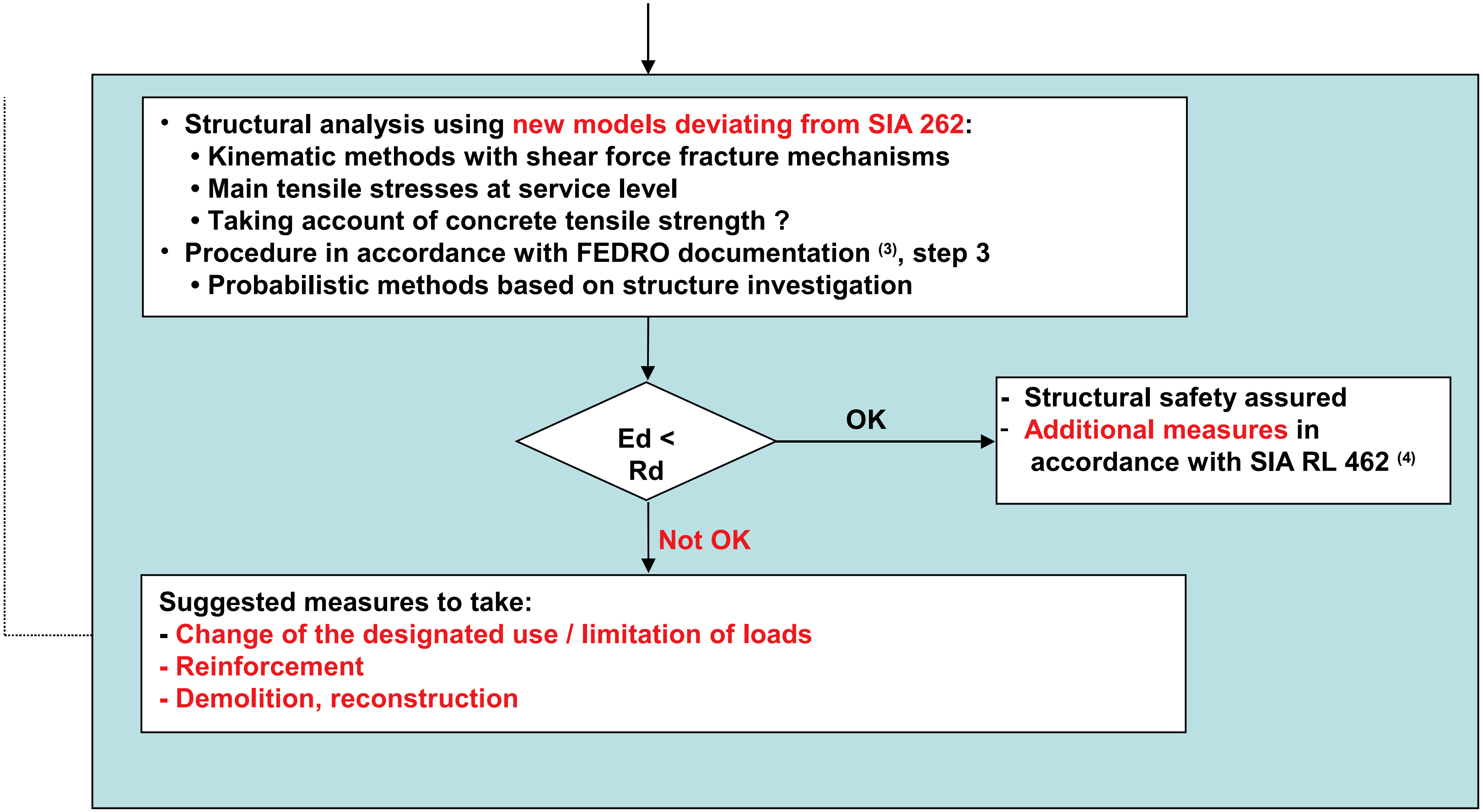
Not OK ↓

- Meeting with specialist bridge engineers from the head office
- If necessary call for support from external experts

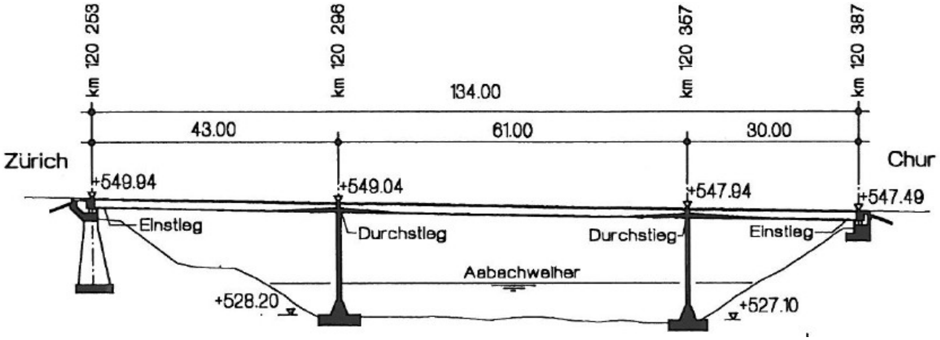
Next Page

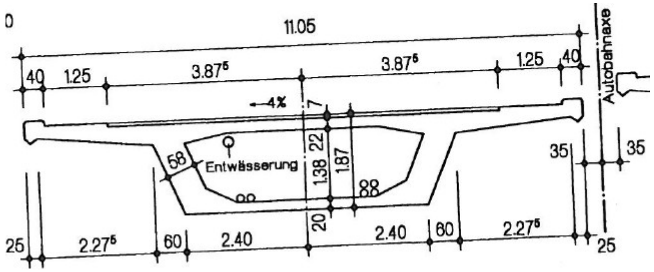
# Procedure for strength evaluation of existing concrete structures – Step 5

Step 5



# Case study – N3.1.1 Aabachweiher bridge (canton of Zurich)



# Case study – Design loads and related internal moments and forces

**Relevant internal design forces located in central span at pillar Chur**

| | Bending moments $M_d$ | Shear force (including torsion) $V_{d,tot}$ |
|---|---|---|
| Σ Loads<br>$\gamma_G$=1.20, $\gamma_Q$=1.50 | -86,207 kNm<br>100% | 9,852 kN<br>100% |
| Traffic loads with $\gamma_Q$=1.50<br>(updated load model ) | -15,736 kNm<br>18% | 2,385 kN<br>24% |

**The table shows the relevant internal design bending moments and shear forces under the updated traffic and updated permanent dead loads according to the SIA directive 462 ($\gamma_G$=1.20 instead of 1.35). The influences of traffic loads vary for this bridge between 18% for moments and 24% for shear forces.**

# Basis of structural safety for new and existing structures according to SIA 260 and 262

**Structural safety can be considered as verified for an ultimate state design , if the following criteria is fulfilled:**

$$E_d \leq R_d$$

**Where:**
$E_d$ **is the dimensioning value of an action effect**
$R_d$ **is the dimensioning value of the ultimate strength**

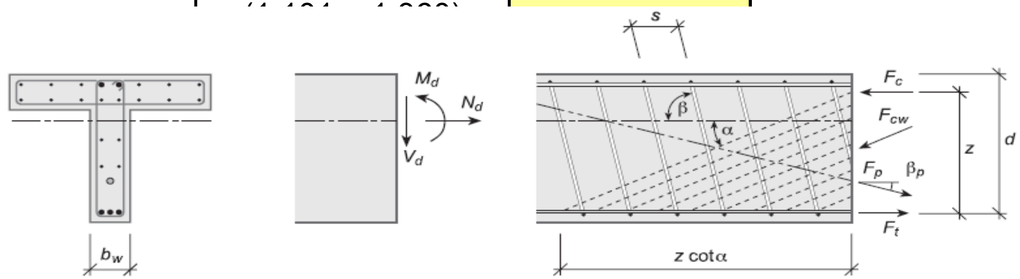
**For existing structures in the Swiss codes the structural safety for the remaining service life is expressed by the conformity factor:**

$$n = (R_{d,\,act.} / E_{d,\,act.}) \geq 1$$

**Where:**
$E_{d,\,act.}$ **is the updated dimensioning value of an action effect**
$R_{d,\,act.}$ **is the updated dimensioning value of the ultimate strength**

# Shear strength evaluation with models based on stress fields according to SIA 262

| Diagonal slope α | Design shear force pillar Chur | Shear reinforcement | | Concrete stress diagonals | |
|---|---|---|---|---|---|
| | $V_{d,tot}$ | Shear strength $V_{Rd,s}+\Delta V_{Rd,p}$ | Conformity factor | Shear strength $V_{Rd,c}+\Delta V_{Rd,p}$ | Conformity factor |
| 25° | 4,513 kN | 2,461 kN [illegible] | **0.55** | 6,580 kN (5,220 + 1,360) | **1.46** |

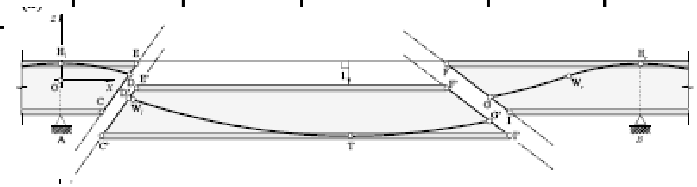



**With a conventional variable truss model the stirrup reinforcement provides only 55% of the required shear strength. It was established that in the webs of the girder box the stirrup reinforcement was insufficient and poorly anchored.**

**The use of truss models with constant slope for the shear design of new structures allows to guarantee a strength capacity on the safe side, but it represents just a lower-bound of the effective strength limit (P. Stoffel, Federal Institute of Technology, Zürich, 2000).**

# Shear strength evaluation considering models with potential fracture mechanisms

| Section at pillar Chur | Relevant fracture line | | Design shear force [kN] | Shear strength [kN] | | | | Conformity factor |
|---|---|---|---|---|---|---|---|---|
| | n | α | $V_{d,tot}$ | $V_{Rd,s}$ | $\Delta V_{Rd,p}$ | $V_{Rd,c}$ | $V_{Rd,tot}$ | |
| - lower vaulted deck | 16 | 28.6° | 4,755 | 1,017 | 1,378 | 2,212 | 4,608 | 0.97 |
| + lower vaulted deck | 16 | 28.6° | 4,755 | 1,017 | 1,378 | 2,641 | 5,036 | 1.06 |



Web-compression-fracture-mechanism according to Ph. Stoffel – Zur Beurteilung der Tragsicherheit bestehender Stahlbetonbauten, ETHZ, 2000

**The kinematic method of the plasticity theory is based on kinematically permissible state of displacement where the energy of the external forces is compared with dissipated energy of the reinforcement, prestressing cable and the concrete. This method was applied and tested for the Europa Bridge in Zurich at Federal Institute of Technology, Zurich, 1996, and provides an upper-bound limit of the shear strength capacity.**

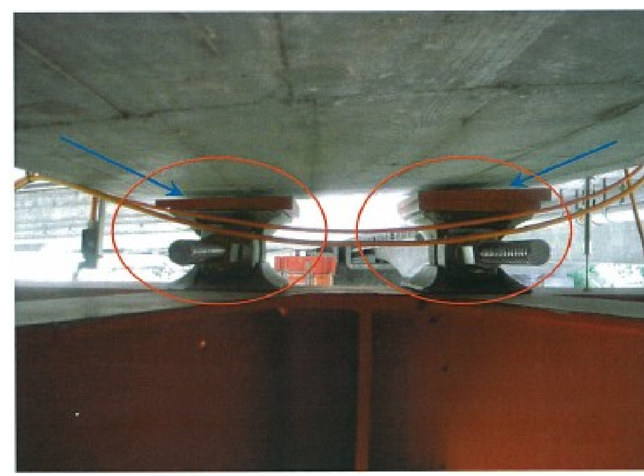
# Urgent measures in case of “brittle fracture” risk Stadtergasse bridge (canton of Saint-Gallen

If the extreme compressive stress in concrete is critical by non-ductile structural members under design loads, preventive measures against brittle failure should be considered.

The Stadtergasse bridge in Mels is a three span continuous highly post-tensioned concrete bridge, built in 1961. No signs in term of deflections or cracks show a danger of collapse. By the routine structural analysis before the rehabilitation it was detected a critical shear strength far below the prevailing code requirements and the ductility criteria of the cross-section was not satisfied.

Preventive measures: scaffolding towers have been put in place to support the deck in case of failure

Instrumentation and a monitoring enables early warning and intervention on the motorway traffic.



# Conclusions

- The evaluation of existing bridges is a highly demanding task and major challenge for engineers, compared with the design of new structures on the basis of current standards.
- The determination of the actual load bearing capacity of existing bridges is of considerable importance for the choice of corrective measures and has a major impact on the associated costs of the rehabilitation.
- In the case of prestressed concrete bridges constructed prior to 1970, conventional methods for the evaluation of the shear resistance often show an inadequate structural safety compared with the relevant standards.

# Conclusions

- The method of evaluation of the shear capacity, based on potential failure mechanisms is a possible evaluation criteria for existing concrete structures and can permit to avoid expensive strengthening works.

- In accordance with the currently applicable SIA standards, the upper-bound analysis should be carried out only for simple cases.

- FEDRO promotes the research at the Swiss Bridge Research Workgroup (AGB), and further research has been scheduled to find solutions for the evaluation area of shear capacity of existing prestressed bridges.


Thank you for your attention!