Institute of Transport Economics
Norwegian Centre for Transport Research

Technical Study of collision protection for bus drivers

Development of new solution trends for collision protection

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2096/2025

Title:	Technical Study of collision protection for bus drivers : Development of new solution trends for collision protection
Tittel:	Teknisk studie av kollisjonsbeskyttelse for bussjåfører : Utvikling av nye løsningstilnærminger for kollisjonsbeskyttelse
Author:	Manuel Laso, Tor-Olav Nævestad
Date:	05.2025
TØI Report:	2096/2025
Pages:	32
ISSN Electronic:	2535-5104
ISBN Electronic:	978-82-480-1374-7
Funded by:	Statens vegvesen
Project:	5475 – Collision protection
Project Manager:	Tor-Olav Nævestad
Quality Manager:	Trine Dale
Commissioning:	Trude Kvalsvik
Research Area:	Safety, Security and Resilience
Keywords:	Bus safety, collision protection, bus drivers

Summary

The main objectives of this study are to provide a technical study of collision protection for bus drivers, and to develop new solution trends for collision protection. The basis for the technical study is formed by three in-depth reports from the Norwegian Safety Investigation Authority (NSIA), focusing on the 2017 Nafstad, 2021 Tangen and 2022 Fredrikstad bus accidents in Norway. The current report 1) Suggests seven measures to improve crash compatibility, 2) Discusses the position of the driver, 3) Proposes reinforcements in bus structures, 4) Proposes reinforcement of front grill and floor of buses, and 5) Proposes reinforcement of the roof. It is concluded that simulations and testing are needed to refine these solutions and to ensure their effectiveness across a wide range of collision scenarios.

Kort sammendrag

Hovedmålene med denne studien er å gjennomføre en teknisk studie av kollisjonsbeskyttelse for bussjåfører og utvikle en ny modell for kollisjonsbeskyttelse. Grunnlaget for den tekniske studien er de tre dybderapportene fra Statens havarikommisjon (NSIA), med fokus på bussulykkene i Nafstad (2017), Tangen (2021) og Fredrikstad (2022) i Norge. Foreliggende rapport 1) Foreslår syv tiltak for å forbedre kollisjonskompatibilitet, 2) Diskuterer sjåførens plassering, 3) Foreslår forsterkninger i busstrukturen, 4) Foreslår forsterkning av frontgrillen og gulvet, og 5) Foreslår forsterkning av taket. Vi konkluderer med at simuleringer og testing er nødvendig for å foredle disse løsningene og sikre deres effektivitet på tvers av et bredt spekter av kollisjonsscenarier.

Preface

The present report is one of several reports provided by TØI in a project focusing on bus driver protection in collisions. The Norwegian Ministry of Transport has tasked the Norwegian Public Roads Administration (NPRA) with evaluating proposals for national requirements on bus collision safety, aiming to enhance driver protection in collisions while considering potential effects on passengers and other road users. There are no mandatory EU crashworthiness standards targeting the collision safety of bus drivers. Taking a lead in bus driver safety, Norway adopted UNECE Regulation UN R29.03 for buses as of 01.10.2023. This standard, however, originally applies to trucks, and may not fully address the unique design and operational characteristics of buses. Thus, there is a need to evaluate the suitability of UN R29.03. Particular mention is also made of Regulation UN R93.00, which currently applies only to heavy goods vehicles (front underrun protection), as a measure to be assessed. The Ministry states that the evaluation should also serve as a basis for a potential Norwegian initiative to develop a voluntary international standard.

The NPRA approached the Institute of Transport Economics (TØI) to conduct an analysis of bus collision safety, focusing on how well the driver (and other road users) are protected. The NPRA's contact person for this analysis was Thea Berg-Halsen. We are very grateful for good cooperation and interesting discussions during the project. We also thank the many individuals and organizations in the Norwegian public transport environment for insightful discussions and valuable contributions.

The present report, which provides a technical Study of collision protection for bus drivers, and development of new solution trends for collision protection, has mainly been written by Manuel Laso from the Spanish company IDIADA, with contributions from Tor-Olav Nævestad from TØI, who is also the project manager of the project. Senior researcher Torkel Bjørnskau and director of research, Trine Dale, have quality assured the report.

Oslo, May 2025
Institute of Transport Economics

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TØI Report 2096/2025 • Authors:Manuel Laso, Tor-Olav Nævestad Manuel Laso, Tor-Olav Nævestad• Oslo 2025 • 32 pages

The main objectives of this study are to provide a technical study of collision protection for bus drivers, and to develop new solution trends for collision protection. The basis for the technical study is formed by three in-depth reports from the Norwegian Safety Investigation Authority (NSIA), focusing on the 2017 Nafstad, 2021 Tangen and 2022 Fredrikstad bus accidents in Norway. The current report 1) Suggests seven measures to improve crash compatibility, 2) Discusses the position of the driver, 3) Proposes reinforcements in bus structures, 4) Proposes reinforcement of front grill and floor of buses, and 5) Proposes reinforcement of the roof. It is concluded that simulations and testing are needed to refine these solutions and to ensure their effectiveness across a wide range of collision scenarios. Although there are no mandatory EU crashworthiness standards focusing on bus drivers, Norway took a lead in bus driver safety and implemented the UN R29.03 frontal crash test standard for buses as of 01.10.2023. Our estimations indicate that UN R29.03 crash test design requirements are insufficient and that there is a need for an improved bus front structure. Using the three fatal Norwegian low speed (e.g. ca 30 km/h) bus collisions as point of departure, estimates indicate that energy levels in these collisions were 10 times higher than the energy tolerance level required by UN R29.03. The current report 1) Suggests seven measures to improve crash compatibility, 2) Discusses the position of the driver, 3) Proposes reinforcements in bus structures, 4) Proposes reinforcement of front grill and floor of buses, and 5) Proposes reinforcement of the roof. It is concluded that simulations and testing are needed to refine these solutions and to ensure their effectiveness across a wide range of collision scenarios.

Weaknesses in the collision safety of current bus design

In recent years, the Norwegian Safety Investigation Authority (NSIA[1]) issued three reports on accidents with head-on collisions between buses (AIBN 2019; 2022; 2023). These accidents occurred at Nafstad (2017), Tangen (2021) and Fredrikstad (2022), and all resulted in fatalities.

[1] Previously AIBN

All three accidents further raised questions about weaknesses in the collision safety of current bus designs, and insufficiencies in regulatory requirements for the crashworthiness of buses.

In November 2017, two scheduled buses in opposite directions collided at the exit of the curve at the bottom of the Nafstad slope, on county road 450 (Fv. 450) in Ullensaker municipality.

Both buses had a speed of approx. 33–34 km/h at the time of the collision, and the front of both buses penetrated about a meter into each other. The driver of one bus was killed instantly, and the driver of the other bus was critically injured.

In March 2021, two identical buses in regular service collided in a curve on county road 222 (Fv. 222), near Tangen in Stange municipality. At the entrance of the curve, one of the buses had a speed of approx. 54-57 km/h, whilst the other bus had a speed of approx. 36-37 km/h. Here too, parts of the buses penetrated each other, and one of the drivers died.

In December 2022, two identical buses collided head-on on national highway 110 (Rv. 110) at the Fredrikstad bridge. Even though the buses collided at low speed (approx. 32 km/h and 35 km/h respectively), the accident resulted in one driver being killed and one driver being critically injured. The two passengers in one bus suffered minor injuries.

Although head-on collisions where a bus is one of the involved vehicles only account for 2-3% of all road traffic fatalities in Norway, the accidents mentioned above, together with earlier accidents (e.g. at Fardal in August 2013), raise particular concerns. This is because the collisions resulted in both fatalities and a lot of material damage despite the relatively moderate speeds and the small overlap on the left-hand side of the buses. Additionally, the buses' construction and crashworthiness characteristics were all deemed to have played a role, and the NSIA considers that the lack of a shock-resistant structure on the front left-hand side of the buses represents a general technical challenge across several bus manufacturers – deemed critical for the safety of bus drivers in head-on bus collisions with small overlap.

Aims

The main objectives of the current study are to provide a technical study of collision protection for bus drivers, and to develop new solution trends for structural improvements in collision protection. The basis for the technical study is formed by the three abovementioned in-depth reports by the NSIA.

The aims of the present study are to:

1) Review the three Norwegian bus accidents studied by the NSIA, and estimate crash energy
2) Review bus and truck regulations for passive safety
3) Propose measures to improve the collision protection of bus drivers

Estimation of impact energy

Despite the introduction of new regulations in Norway requiring frontal impact tests (i.e. UN R29.03), these do not address the structural weaknesses observed in the aforementioned accidents. The impact energy of each of these three accidents was calculated based on the information given by the reports of the accidentology. The level of energy produced in these three accident scenarios can be considered equivalent, considering the boundary conditions of all buses. The level is estimated to be about 10 times higher (approx. 550 kJ) than the energy values prescribed in Regulation UN R29.03 (55 kJ).

We have estimated the ideal energy absorption capabilities for transit buses in collision scenarios. These vehicles should be engineered to dissipate kinetic energy across a broad spectrum, ranging from approximately 424 kJ when colliding with compact vehicles (mass around 1,333 kg) to as much as 2,000 kJ in impacts involving larger vehicles (mass approximately 12,000 kg). Based on these estimations and the analyses of accidents, we propose changes to the bus structure.

Measures to improve collision protection

Improvement of crash compatibility

The primary problem observed in the three bus accidents is the inadequate energy absorption by vehicle structures during collisions. In the analysed cases, the bus structures tend to deform and open up upon impact, leading to severe intrusions into the colliding vehicles. What's particularly alarming is the disproportionate severity of both structural damage and personal injuries, especially considering the relatively low impact speeds in these incidents.

A common factor in all three accidents was the small overlap of the impacts. This scenario concentrates the impact energy in a very limited area of the vehicle's front, magnifying the destructive forces and exacerbating the damage caused. The focused energy transfer in these small overlap collisions poses a significant challenge to current vehicle design paradigms.

One of the most critical issues identified is the behaviour of the bus's frontal structure during impact. The transversal profile, which serves as the sole structural element connecting the sides at the front of the bus, detaches during the collision. This structural failure leaves the edge of the side panel unrestrained, effectively turning it into a 'battering ram'. The resistance and rigidity of this now-detached side panel cause it to penetrate the opposing vehicle with devastating consequences, resulting in severe damage and increased risk of injury to occupants.

To address these critical safety concerns, several potential solutions can be considered to improve crash compatibility.

1. **Enhanced Structural Integrity**: Developing more robust connections between the transverse profile and the side panels of buses is crucial. This could involve redesigning the frontal structure to maintain its integrity during impacts, preventing the 'battering ram' effect observed in the studied accidents.
2. **Energy Absorption Zones**: Incorporating dedicated energy absorption zones in the front structure of buses could help manage impact forces more effectively. These zones should be designed to deform progressively, absorbing energy while maintaining the overall structural integrity of the vehicle.
3. **Small Overlap Impact Testing:** Introducing mandatory small overlap impact testing for buses, similar to tests now common for passenger cars, could drive improvements in design to better handle these challenging impact scenarios.
4. **Advanced Materials:** Exploring the use of advanced, energy-absorbing materials in bus construction could provide better protection without significantly increasing vehicle weight.
5. **Compatibility Design Standards:** Developing specific standards for vehicle compatibility between buses and smaller vehicles could lead to designs that interact more safely during collisions.
6. **Mandatory Implementation of Regulation UN R93.00**: The United Nations Economic Commission for Europe Regulation No. 93 addresses front underrun protection on heavy goods vehicles. While primarily designed for trucks, adapting and mandating this

regulation for buses could significantly improve their compatibility with smaller vehicles in frontal collisions. The regulation UN R93.00 standard requires the installation of a front underrun protection device, which could help distribute impact forces more evenly and prevent smaller vehicles from under-riding the bus in a collision.

7. **Integration with Towing Hook regulation:** Combining requirements from UN R93.00 with existing towing hook regulation (EU R1005/2010) could provide a dual-purpose solution. By designing a robust front structure that serves both as an underrun protection device and a standardized towing point, we could enhance both safety and utility. This integrated approach would ensure that the frontal structure of buses is strengthened without compromising serviceability.

Implementing these solutions would require a coordinated effort from vehicle manufacturers, regulatory bodies, and safety organizations. By mandating the R93.00 standard for buses, combined with enhanced towing hook regulations and the additional measures suggested, we could significantly improve the safety outcomes in bus-involved collisions.

The goal is to create bus structures that not only protect their occupants but also minimize damage and injury risk to occupants of other vehicles involved in collisions. This holistic approach to vehicle safety design is essential as we strive to reduce the severity of road accidents and improve overall traffic safety. Further research and real-world testing will be crucial in refining these solutions and ensuring their effectiveness across a wide range of collision scenarios.

The position of the driver

The position of the driver is quite important with respect to the severity of accidents. In urban buses, the height of the driver position is approximately 800mm to 1000mm, while in coach buses the driver position is approximately 1400mm-1600mm high.

In the case of urban buses, it would be possible to raise the position of the driver slightly, but ergonomics would have to be checked in order to be able to carry out passenger control functions, such as collecting admission. In any case, this increase in height would be very small. Positioning the driver further back would be even more complicated, since that would mean movement restrictions due to the small distance from the seat to the front wheelarch position. In some specific cases it would mean eliminating the capacity of a row of seats, which would make the bus less competitive in the market.

Reinforcements in the structure

In the three studied Norwegian bus accidents, one can see that bus lateral side structures are totally intruding opposite buses, by literally ‘cutting’ the structure, like a knife does. The level of severity for this type of accident is extremely high, so structural design, reinforcements and materials should be focused on avoiding this situation as much as possible to improve crash compatibility. Structural reinforcements should be focused on the driver side and avoid mainly two things: One is to prevent the transversal tubes in the front low area to be detached, and the second to avoid the collapse of connection hinges to be close to the driver. The strategy could be to use a ‘semi-cage’ open structure, protecting the lower area, as well as providing a better connection with the roof.

In addition, the amount of energy absorption by the structure is important to manage. The reality of these accidents shows that energy levels are much higher than the energy level proposed by the test type-A, required by regulation UN R29.03, which collides a pendulum impactor of 55kJ over the whole width of front structure. The definition of a specific test or tests to evaluate bus safety in more realistic conditions would be necessary.

Reinforcement of front grill and floor

In the realm of bus crash safety, one critical area of concern is the behaviour of the frontal structure during collision events. Current designs often result in the front of the bus transforming into a hazardous ‘lance’ or ‘battering ram’ upon impact. This transformation has lethal consequences, particularly for the drivers involved in such collisions.

The primary issue lies in the lower frontal structure of buses, which currently lacks adequate connections and reinforcement. During a high-impact crash, this weakness allows the front end to collapse and protrude forward, effectively creating a penetrating force that significantly increases the severity of the collision. This phenomenon not only endangers the bus occupants but poses an extreme threat to the occupants of other vehicles involved in the crash, especially those in smaller passenger cars.

To mitigate this risk, it is imperative that we focus on improving the connections within the lower frontal structure of buses. Enhanced structural integrity in this area would help maintain the bus’s shape during a collision, preventing the formation of the dangerous ‘lance" effect’. This improvement would involve reinforcing key points of the frontal frame and implementing more robust joining techniques to ensure that the structure remains cohesive under impact forces.

One promising approach to addressing this issue involves leveraging the inherent strength of the towing hook mount point, mandatory for buses under regulation EU R1005/2010. The towing hook point area, designed to withstand significant forces, could serve as the starting point to extend the frontal structure reinforcement and to be used as the front underrun protection, aiming to reduce the risk of smaller vehicles under-riding bus structures in the event of frontal collisions.

Currently, the front underrun protection system is only mandatory for trucks, not bus vehicles. In this case, our proposal is to extend this requirement, to combine the requirements of R1005/2010 and UN R93.00, and to develop a frontal structure to effectively increase the crumple zone and energy absorption capabilities of the bus.

This extended structure would serve multiple purposes:

1. It would prevent fatalities caused by the intrusion of the lateral panel of the collision partner into the bus driver’s cabin by providing a controlled deformation zone.
2. It would offer better protection to the bus driver and passengers by managing impact forces more effectively.
3. Most importantly, it would significantly enhance the safety of occupants in smaller vehicles involved in collisions with buses.

Implementing such a design would require careful engineering to balance the need for increased frontal protection with considerations of weight, aerodynamics, and overall vehicle performance. However, the potential benefits in terms of improved safety outcomes make this a worthwhile endeavour.

Summarizing, by focusing on strengthening the lower frontal connections, extending the front structure from the towing hook point (EU R1005/2010), and meeting UN R93.00 requirements, the lethality of bus-involved collisions can probably be significantly reduced. This approach not only protects bus occupants, but also offers vital protection to other road users, particularly those in smaller vehicles who are most vulnerable in such crash scenarios.

Reinforcement of the roof

Looking at the three discussed Norwegian bus accidents, upper roof connections were detached from buses' lateral structures. From the accident at Tangen (2021), we could additionally observe that the roof structure was bended down due to the big deformation occurring during the crash. The stiffness of the roof structure and the quality of the connection with the front pillar is assumed to have a big impact in the safety results during the crash. Our recommendation is to increase the strength of the roof connection with the first arch located in the windscreen, and also the connection with the second safety arch, just behind the driver. In addition, the use of reinforcement brackets for the tube connection, and the application of a good weld location strategy, would help to keep the big deformations out from welded areas so the risk of detachment of connections could be reduced significantly.

Need for future studies

The present study is a desk study, and it is necessary to implement a deeper study based on simulations and/or testing to validate our recommendations and suggestions. It is important to execute a set of simulations considering different overlaps and angles to catch the worst-case scenario, and from this point to define proper tests to be applied. Further research and real-world testing will be crucial in refining our suggested solutions and in ensuring their effectiveness across a wide range of collision scenarios. By addressing these compatibility issues, we can work towards a future where the severity of bus-involved accidents is significantly reduced, including at lower impact speeds, thereby enhancing road safety for all vehicle occupants.

Transportøkonomisk institutt
Stiftelsen Norsk senter for samferdselsforskning

NORSK **Sammendrag**

Teknisk studie av kollisjonsbeskyttelse for bussjåfører

Utvikling av nye løsningstilnærminger for kollisjonsbeskyttelse

TØI rapport 2096/2025 • Forfattere: Manuel Laso, Tor-Olav Nævestad • Oslo, 2025 • 32 sider

Hovedmålene med denne studien er å gjennomføre en teknisk studie av kollisjonsbeskyttelse for bussjåfører og utvikle en ny modell for kollisjonsbeskyttelse. Grunnlaget for den tekniske studien er de tre dybderapportene fra Statens havarikommisjon (NSIA), med fokus på buss-ulykkene i Nafstad (2017), Tangen (2021) og Fredrikstad (2022) i Norge. Selv om det ikke finnes obligatoriske EU-standarder for kollisjonssikkerhet som fokuserer på bussjåfører, har Norge tatt en ledende rolle innen bussjåførens sikkerhet og implementert R29.03-frontkollisjons-testen for busser fra 01.10.2023. Våre beregninger indikerer at R29.03-kollisjonstestens designkrav er utilstrekkelige, og at det er behov for en forbedret bussfrontstruktur. Vi bruker de tre nevnte dødelige norske busskollisjonene med relativt lav hastighet som utgangspunkt. Våre estimater viser at energinivået i disse kollisjonene var ti ganger høyere enn energitole-ransenivået som kreves av R29.03. Foreliggende rapport 1) Foreslår syv tiltak for å forbedre kollisjonskompatibilitet, 2) Diskuterer sjåførens plassering, 3) Foreslår forsterkninger i busstrukturen, 4) Foreslår forsterkning av frontgrillen og gulvet, og 5) Foreslår forsterkning av taket. Vi konkluderer med at simuleringer og testing er nødvendig for å foredle disse løsningene og sikre deres effektivitet på tvers av et bredt spekter av kollisjonsscenarier.

Svakheter i kollisjonssikkerheten til dagens bussdesign

I de senere år har Statens havarikommisjon (NSIA[2]) utgitt tre rapporter om ulykker med front-kollisjoner mellom busser (AIBN 2019; 2022; 2023). Disse fant sted ved Nafstad (2017), Tangen (2021) og Fredrikstad (2022). Alle de tre ulykkene resulterte i dødsfall, og reiste spørsmål om svakheter i kollisjonssikkerheten til dagens bussdesign og mangler i regelverkskrav for bussers kollisjonssikkerhet.

I november 2017 kolliderte to rutebusser som kom i motsatt retning ved utgangen av kurven nederst i Nafstadbakken, på fylkesveg 450 (Fv. 450) i Ullensaker kommune. Begge bussene hadde en hastighet på ca. 33–34 km/t ved kollisjonstidspunktet, og frontene på begge busser

[2] Tidligere AIBN

penetrerte omtrent én meter inn i hverandre i sammenstøtet. Sjåføren på den ene bussen omkom momentant, og sjåføren på den andre bussen ble kritisk skadet.

I mars 2021 kolliderte to identiske rutebusser i en kurve på fylkesveg 222 (Fv. 222) nær Tangen i Stange kommune. Ved inngangen til kurven hadde den ene bussen en hastighet på ca. 54–57 km/t, mens den andre bussen hadde en hastighet på ca. 36–37 km/t. Også her penetrerte deler av bussene hverandre, og én av sjåførene døde.

I desember 2022 kolliderte to identiske busser front mot front på riksveg 110 (Rv. 110) ved Fredrikstad-bruen. Selv om bussene kolliderte i lav hastighet (ca. 32 km/t og 35 km/t), resulterte ulykken i at én sjåfør døde og én sjåfør ble kritisk skadet. De to passasjerene i en av bussene fikk mindre skader.

Selv om frontkollisjoner der en buss er involvert kun utgjør 2-3 % av alle trafikkdødsfall i Norge, vekker de nevnte ulykkene, sammen med tidligere ulykker (f.eks. ved Fardal i august 2013), spesielle bekymringer. Dette skyldes at kollisjonene resulterte i både dødsfall og betydelige materielle skader, til tross for de relativt moderate hastighetene og små overlappene på venstre side av bussene. I tillegg ble bussens konstruksjon og kollisjonsegenskaper ansett for å ha spilt en rolle, og havarikommisjonen vurderer at mangelen på en støtsikker struktur på venstre frontside av bussene representerer en generell teknisk utfordring hos flere bussprodusenter – ansett som kritisk for sikkerheten til bussjåfører i frontkollisjoner med små overlapp.

Målene med studien

Hovedmålene med studien er å gjennomføre en teknisk studie av kollisjonsbeskyttelse for bussjåfører og å utvikle en ny modell for kollisjonsbeskyttelse. Grunnlaget for den tekniske studien er de tre dybdestudiene fra Statens havarikommisjon som fokuserer på bussulykkene i Nafstad (2017), Tangen (2021) og Fredrikstad (2022).

Målene med denne studien er:

1) Å gjennomgå de tre norske bussulykkene undersøkt av havarikommisjonen og estimere kollisjonsenergien.
2) Å vurdere buss- og lastebilreguleringer for passiv sikkerhet.
3) Å foreslå tiltak for å forbedre kollisjonsbeskyttelsen for bussjåfører.

Beregning av kollisjonsenergi

Til tross for innføringen av nye reguleringer i Norge som krever frontkollisjonstester (dvs. UN R29.03), adresserer disse ikke de strukturelle svakhetene observert i de nevnte ulykkene. Kollisjonsenergien i hver av de tre ulykkene ble beregnet basert på informasjonen gitt i ulykkesrapportene. Energien som ble generert i disse tre ulykkesscenarioene kan betraktes som sammenlignbar, gitt de samme betingelsene for alle busser. Nivået er om lag 10 ganger høyere (ca. 550 kJ) enn energitoleranseverdiene foreskrevet i regelverk UN R29.03 (55 kJ).

Vi har estimert de ideelle energidempingsegenskapene for busser i kollisjonsscenarioer. Disse kjøretøyene bør utformes for å kunne absorbere kinetisk energi over et bredt spekter, fra omtrent 424 kJ ved kollisjoner med lette kjøretøy (masse rundt 1 333 kg) til så mye som 2 000 kJ ved sammenstøt med større kjøretøy (masse ca. 12 000 kg). Basert på disse beregningene og analysene av ulykkene foreslår vi endringer i bussens struktur.

Tiltak for å forbedre kollisjonsbeskyttelse

Forbedring av kollisjonskompatibilitet

Hovedproblemet som ble observert i de tre bussulykkene er utilstrekkelig energiabsorpsjon i kjøretøystrukturen under kollisjoner. I de analyserte tilfellene tenderte busstrukturene til å deformeres og åpnes ved sammenstøt, noe som førte til alvorlige intrusjoner i det kolliderende kjøretøyet. Det som er spesielt alarmerende, er den uforholdsmessige alvorlighetsgraden av både strukturelle skader og personskader, spesielt med tanke på de relativt lave kollisjonshastighetene i disse hendelsene.

Et fellestrekk i alle tre ulykkene var små overlappkollisjoner. Disse scenarioene konsentrerer kollisjonsenergien i et svært begrenset område av kjøretøyets front, noe som forsterker de destruktive kreftene og forverrer skadene. Den fokuserte energioverføringen i disse små overlappkollisjonene utgjør en betydelig utfordring for dagens kjøretøydesign.

Et av de mest kritiske problemene som ble identifisert er oppførselen til bussens frontstruktur under sammenstøt. Tverrprofilen, som fungerer som det eneste strukturelle elementet som forbinder sidene foran på bussen, løsner under kollisjonen. Denne strukturelle svikten etterlater kanten av sidepanelet uten støtte, og forvandler det effektivt til en rambukk eller lanse. Motstanden og stivheten til dette nå-løse sidepanelet fører til at det penetrerer det motsatte kjøretøyet med ødeleggende konsekvenser, noe som resulterer i alvorlige skader og økt risiko for personskader.

Forslag til løsninger for å forbedre kollisjonskompatibilitet:

1) **Forbedret strukturell integritet:** Sterkere koblinger mellom tverrprofilen og sidepanelene kan opprettholde strukturell integritet under kollisjoner og forhindre at de gjenværende delene fungerer som en rambukk eller lanse i møte med et annet kjøretøy.
2) **Energidempingssoner:** Implementering av dedikerte energidempingssoner i bussens frontstruktur kan effektivt håndtere kollisjonskreftene og absorbere energi gradvis.
3) **Tester for små overlappkollisjoner:** Innføring av obligatoriske tester for busskollisjoner med små overlapp, tilsvarende de testene som er vanlige for personbiler, kan forbedre designet for å håndtere utfordrende kollisjonsscenarioer.
4) **Avanserte materialer:** Utforsking av bruken av energiabsorberende materialer i busskonstruksjon kan forbedre beskyttelsen uten å øke kjøretøyets vekt betydelig.
5) **Kompatibilitetsdesignstandarder:** Utvikling av spesifikke standarder for kompatibilitet mellom busser og mindre kjøretøy kan fremme sikrere interaksjoner under kollisjoner.
6) **Obligatorisk implementering av UN R93**: FN-regulativ nr. 93.00 adresserer underkjøringshinder i fronten på tunge kjøretøy. Tilpasning og implementering av dette regelverket for busser kan forbedre kompatibiliteten med mindre kjøretøy ved frontkollisjoner. R93.00-standarden krever installasjon av et frontunderkjøringsvern, som kan fordele kollisjonskreftene jevnere og forhindre at mindre kjøretøy kjører inn under bussen.
7) **Integrasjon med regulering for slepekrok**: Kombinasjonen av R93.00-kravene med eksisterende regulering for slepekrok (EU R1005/2010) kan gi en dobbel løsning. En robust frontstruktur kan fungere både som underkjøringsvern og som en standardisert slepekrok.

Implementering av disse løsningene krever et koordinert samarbeid mellom kjøretøyprodusenter, reguleringsorganer og sikkerhetsorganisasjoner. Ved å gjøre R93.00 obligatorisk for busser, i kombinasjon med forsterkede slepekrokreguleringer og de foreslåtte tiltakene, kan vi forbedre sikkerhetsresultatene i kollisjoner der busser er involvert.

Målet er å utvikle bussstrukturer som ikke bare beskytter passasjerene, men som også reduserer skaderisikoen for passasjerer i andre kjøretøy. En helhetlig tilnærming til kjøretøysikkerhet er avgjørende for å redusere alvorlighetsgraden av trafikkulykker og forbedre den generelle trafikksikkerheten. Ytterligere forskning og realistisk testing vil være avgjørende for å finjustere disse løsningene og sikre deres effektivitet i et bredt spekter av kollisjonsscenarier.

Førerens posisjon

Førerens posisjon er svært viktig for alvorlighetsgraden av ulykker. I bybusser ville det vært relevant å heve førerposisjonen noe, men ergonomiske hensyn må ivaretas for å kunne utføre passasjerkontrollfunksjoner, som billettkontroll.

Forsterkninger i strukturen

I de tre studerte norske bussulykkene kan man se at bussens sidepaneler trengte inn i den motsatte bussen ved bokstavelig talt å 'skjære' gjennom strukturen, som en kniv. Alvorlighetsgraden ved denne typen ulykker er ekstremt høy, og derfor er det viktig å fokusere på strukturelt design, forsterkninger og materialer for å unngå detteså langt som mulig og for å forbedre kollisjonskompatibiliteten.

Strukturelle forsterkninger bør hovedsakelig fokusere på sjåførens side og må unngå to spesifikke problemer:

1) Hindre at de tverrgående rørene i den nedre frontstrukturen løsner.
2) Hindre kollaps av forbindelsespunktene (hengsler) som er nær sjåføren.

En strategi kan være å bruke en 'semi-bur'-struktur som er åpen, men som beskytter det nedre området og samtidig sikrer bedre tilkobling til taket.

Videre er energiabsorpsjon en viktig utfordring som må løses. Realiteten i ulykkene viser at energinivåene er langt høyere enn energinivået som foreslås i UN R29.03 (type-A), som krever 55 kJ over hele bredden av frontstrukturen. Det er nødvendig å definere spesifikke tester for å evaluere bussikkerhet under mer realistiske forhold. Videre forskning og testing bør inkludere forskjellige overlapp og vinkler for å identifisere de verste scenariene, og basert på dette definere passende tester.

Forsterkning av nedre front og gulv

Et kritisk område innen busskollisjonssikkerhet er hva som skjer med frontstrukturen under kollisjonshendelser. Dagens design resulterer ofte i at fronten av bussen forvandles til en farlig 'lanse' eller 'rambukk' ved sammenstøt. Denne transformasjonen har dødelige konsekvenser, spesielt for sjåførene som er involvert i slike kollisjoner.

Hovedproblemet ligger i den nedre frontstrukturen til busser, som for øyeblikket mangler tilstrekkelige koblinger og forsterkninger. Under en kollisjon med høyt energinivå gjør denne svakheten at fronten kollapser og stikker fremover, og skaper en penetrerende kraft som øker alvorlighetsgraden av kollisjonen betydelig. Dette fenomenet utgjør ikke bare en fare for bussens passasjerer, men utgjør også en ekstrem trussel for passasjerene i andre kjøretøy involvert i kollisjonen, spesielt de i mindre personbiler.

For å redusere denne risikoen er det viktig å fokusere på å forbedre koblingene i den nedre frontstrukturen til busser. Forbedret strukturell integritet i dette området vil bidra til å opprettholde bussens form under en kollisjon og forhindre dannelsen av den farlige 'lanse'-effekten. Denne forbedringen vil innebære å forsterke nøkkelpunkter i frontstrukturen og implementere mer robuste sammenføyningsteknikker for å sikre at ikke strukturene knekker eller løsner fra hverandre under kollisjonskrefter.

En lovende tilnærming til å adressere dette problemet er å utnytte den iboende styrken til slepekrokens monteringspunkt, som er obligatorisk for busser i henhold til regelverket EU R1005/2010. Slepekrokens monteringsområde er designet for å tåle betydelige krefter, og kan fungere som utgangspunkt for å forlenge forsterkningen av frontstrukturen og brukes som frontunderkjøringshinder. Målet er å redusere risikoen for at mindre kjøretøy kjører under bussens struktur ved frontkollisjoner.

For øyeblikket er systemet for frontunderkjøringshinder kun obligatorisk for lastebiler og ikke for busser. Forslaget er derfor å utvide dette kravet, kombinere kravene i R1005/2010 og R93.00, og utvikle en frontstruktur som effektivt øker deformasjonssonen og energidempings-kapasiteten til bussen.

Denne utvidede strukturen vil ha flere formål:

1) Forhindre dødsfall forårsaket av intrusjon av sidepanelet til kollisjonspartneren inn i bussjåførens kabin ved å tilby en kontrollert deformasjonssone.
2) Gi bedre beskyttelse til bussjåføren og passasjerene ved å håndtere kollisjonskrefter mer effektivt.
3) Viktigst av alt, betydelig forbedre sikkerheten for passasjerene i mindre kjøretøy involvert i kollisjoner med busser.

Implementering av et slikt design krever nøye ingeniørarbeid for å balansere behovet for økt frontbeskyttelse med hensyn til vekt, aerodynamikk og kjøretøyets generelle ytelse. De potensielle fordelene i form av forbedrede sikkerhetsresultater gjør dette imidlertid til et potensielt effektivt tiltak.

Ved å fokusere på å styrke de nedre frontkoblingene, utvide frontstrukturen fra slepekrokens monteringspunkt (EU R1005/2010), og oppfylle kravene i UN R93.00, kan vi antakelig redusere dødeligheten i kollisjoner som involverer busser. Denne tilnærmingen beskytter ikke bare bussenssjåfør og passasjerer, men gir også viktig beskyttelse til andre trafikanter, spesielt de i mindre kjøretøy som er mest sårbare i slike kollisjonsscenarioer.

Forsterkning av taket

De tre rapportene fra Havarikommisjonen viser at i de studerte bussulykkene, løsnet den øvre takkonstruksjonen fra sidekonstruksjonen. Ved Tangen-ulykken i 2021 ble det i tillegg observert at takstrukturen bøyde seg ned på grunn av den store deformasjonen som oppstod under kollisjonen. Stivheten i takstrukturen og kvaliteten på forbindelsen med frontbuen antas å ha stor betydning for sikkerheten under kollisjonen.

Anbefalingen er å øke styrken på takforbindelsen med A-stolpen som er plassert ved frontruten, samt forbindelsen med B-stolpen, like bak sjåføren. I tillegg foreslås bruk av forsterkningsbraketter for rørforbindelsene og implementering av en god strategi for sveiseplassering. Dette vil bidra til å holde de store deformasjonene utenfor sveisesonene, noe som betydelig kan redusere risikoen for at forbindelsene løsner.

Behov for fremtidige studier

Denne studien er en «skrivebordsstudie» (dvs. uten tester eller simuleringer) og det er nødvendig å gjennomføre en dypere studie basert på simuleringer og/eller testing for å validere våre anbefalinger og forslag. Det er viktig å utføre et sett med simuleringer som vurderer ulike overlapp og vinkler for å fange opp det verste scenarioet. Fra dette punktet kan de riktige testene defineres og implementeres.

Videre forskning og testing under realistiske forhold vil være avgjørende for å finjustere de foreslåtte løsningene og sikre deres effektivitet i et bredt spekter av kollisjonsscenarier. Ved å ta tak i disse kompatibilitetsutfordringene kan vi bevege oss mot en fremtid der alvorlighets-graden av bussrelaterte ulykker reduseres betydelig, selv ved lavere kollisjonshastigheter. Dette vil dermed bidra til å forbedre trafikksikkerheten for alle kjøretøypassasjerer.

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1 Introduction

1.1 Background

In recent decades, the automotive industry has made significant strides in vehicle safety due to stricter regulations. These have strengthened vehicle frames and encouraged the adoption of innovative technologies. Passenger cars now feature advanced safety systems like seatbelt pretensioners, airbags, and crash-resistant materials. The introduction of Advanced Driver Assistance Systems (ADAS), such as automatic emergency braking and lane-keeping assist, has also helped prevent accidents and reduce collision severity. These improvements have led to a notable decrease in severe injuries and fatalities on the roads.

However, despite these advancements, the progress in the safety of heavy vehicles, especially buses, has not kept pace. The regulations governing safety in this sector have remained relatively unchanged, resulting in a lack of advanced safety equipment in many buses currently on the road. Consequently, passengers and drivers of these vehicles may face a higher risk of injuries in the event of a collision.

Although bus accidents do not account for the majority of road fatalities, three serious incidents involving fatalities occurred within a short period (2017-2022) in Norway. These events share a significant similarity in the nature of the collision, and all resulted in fatal outcomes. This raises concerns about a potential pattern in these accidents, suggesting that the overall safety measures on buses may not be functioning as intended, or that the scenarios for which buses are designed do not align with the realities of the incidents they face.

1.2 Aims

The main objectives of this study are to provide a technical study of collision protection for bus drivers, and to develop new solution trends for collision protection. The basis for the technical study is formed by the three NSIA in-depth reports focusing on the 2017 Nafstad, 2021 Tangen and 2022 Fredrikstad bus accidents in Norway.

The aims of the present study are to:

1) Review the three Norwegian bus accidents studied by the NSIA, and estimate crash energy
2) Review bus and truck regulations for passive safety
3) Propose measures to improve the collision protection of bus drivers

1.3 Accidentology review

Nafstad, 17 November 2017

The first of the accidents, in chronological order, took place in Nafstad on November 17th, 2017. Two identical low-floor buses, both Volvo 8700 models, were traveling along the Fv. 450 interurban road when they collided. The collision was caused by a loss of traction due to ice on the road, leading one of the buses, coming from the east, to skid. Notably, the crash occurred on a section of the road with a slight curve and a moderate slope.

Despite the slight curve in the road, this can be considered a fully frontal collision with an overlap of approximately 1 meter, which is 39.21% of the bus's total width of 2.55 meters. The impact speed was around 34 km/h after the braking systems of both buses were activated. Although the buses were traveling at relatively low speeds of 33-34 km/h, the collision caused significant deformation to both vehicles. The eastbound bus driver tragically lost his life on the spot, while the westbound driver suffered severe injuries after being trapped by the structures of the colliding bus.

Figure 1.1: Nafstad accident location. Layout of the accident [1]

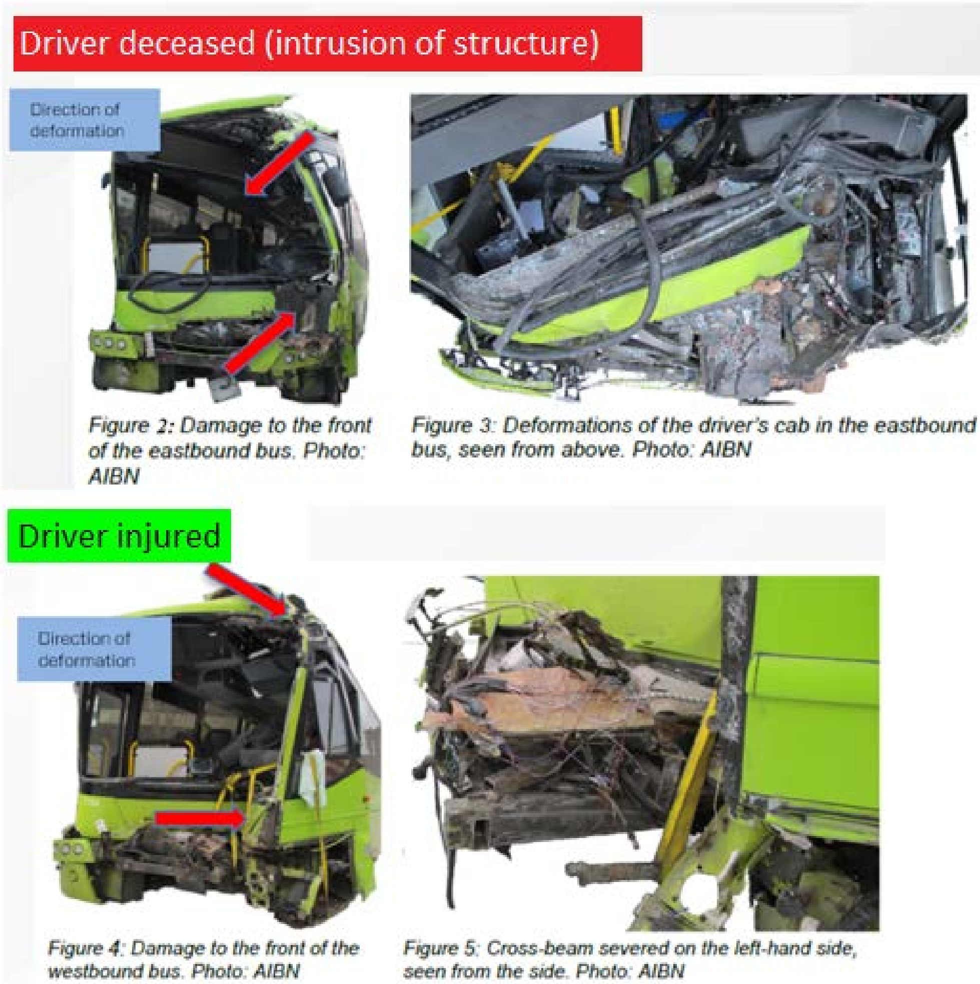

Figure 1.2: Status of buses after the crash [1]

In the accident reports and the graphical documentation of the vehicle conditions, structural failures that led to the drivers' death and injuries can be observed. The main structural intrusion is due to the penetration of the A-pillar into the impacted bus, causing the structure to collapse and, consequently, reducing the driver's survival space. In this case, the bus coming from the west intrudes upon the one coming from the east, which is the most affected. The loading line on the A-pillar is notable in the accident, where the upper joint of one pillar penetrates into the bus, while the structure of the other pillar pushes outward, creating opposite deformation profiles. This event effectively isolates the impact conditions, as it involves two identical vehicles colliding at the same speed, excluding several variables from the equation.

Tangen, 11 March 2021

The second accident occurred on the outskirts of Tangen, on the Fv. 202 road connecting it with Stange, on March 11th, 2021. In this case, similar to the 2017 accident, one of the buses lost control in winter conditions and invaded into the opposite lane, resulting in a head-on collision on the left front sides of both vehicles. Both buses involved were from the same service and were Volvo 8900 models.

The limited visibility in the curve did not help to prevent the accident. As a result, the southbound bus collided at an approximate speed of 27 km/h, while the northbound bus crashed at 42 km/h after both drivers applied the brakes. The impact was primarily frontal, affecting the leftmost edge of both vehicles, with an impacted area estimated between 150-200 mm, which translates to an overlap of about 5% to 8%. The result of the impact conducted the decease of the driver of the southbound bus, whilst the other driver was slightly injured.

Figure 1.3: Tangen accident location. Layout of the accident [2]

The collision primarily involved the left front corners of both buses, causing significant structural damage, particularly in the driver's cabin area. The A-pillar of the northbound bus intruded into the driver's compartment of the other bus, resulting in fatal injuries for the southbound bus driver despite the relatively low speeds. The central section of the vehicles was almost entirely uninvolved in the impact, meaning that all the collision energy was concentrated on the A-pillar of the first arc. As in previous cases, one structure was torn and penetrated, while the other collapsed inward. However, in this instance, the minor overlap allowed the vehicles to keep moving forward.

Figure 1.4: Status of buses after the crash [2]

Fredrikstad, 28 December 2022

On December 28th, 2022, the 3rd similar accident between line buses took place. The accident occurred on national highway Rv. 110 near the Fredrikstad bridge and involved a head-on collision between two identical buses of the MAN Lion's City low entry (2013) model. One of the buses was traveling without passengers, while the other had two passengers on board. Despite the collision occurring at low speed, it resulted in the death of one of the drivers and critical injuries to the other. The passengers only sustained minor injuries.

Figure 1.5: Fredrikstad accident location. Layout of the accident [3]

According to tachograph records, the bus coming from the south impacted at an approximate speed of 32 km/h, while the one approaching from the northeast collided at a speed of 40 km/h. The exact cause of why one of the drivers veered into the opposite lane, leading to the collision, remains unknown. The report from the Norwegian authorities does not specify the overlap involved in the crash. However, an analysis of the images suggests that the impact was intermediate between the incidents accidents in 2017 and 2021, with an overlap estimated to be less than 1 meter on the leftmost side of the vehicles.

The structural analysis of this event suggests conclusions very similar to those of its predecessors. The report indicates a structural collapse of the A-pillar and an opening of the side structures on both buses, causing intrusion and reducing the survival space to zero for the bus that ended up under-neath. In this collision, the seat of the deceased driver was completely displaced from its original position, while the other driver's seat remained in place.

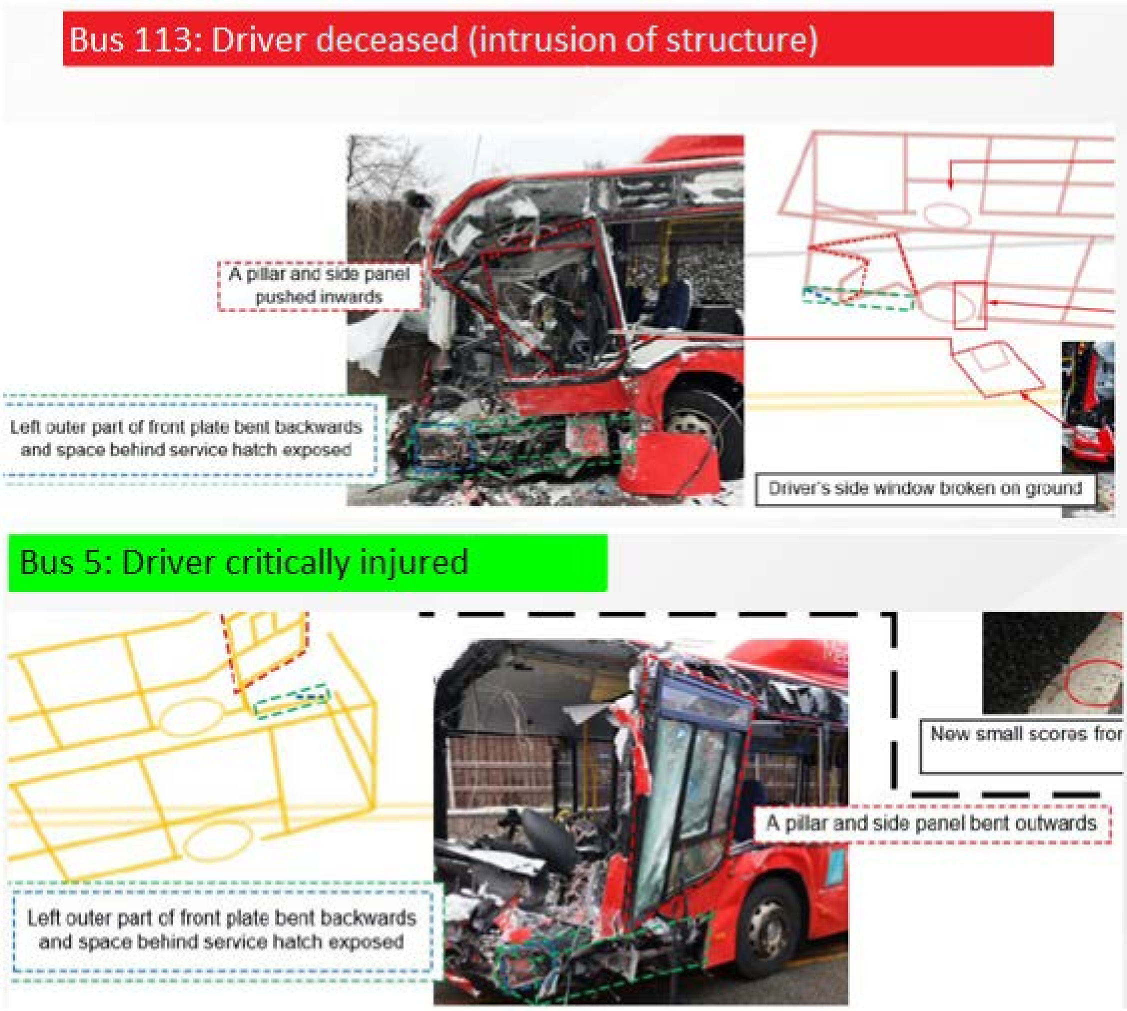

Figure 1.6: Status of buses after the crash [3]

Analysis of the accidents

These accidents highlight a worrying trend where bus structures, particularly in the front corners and A-pillars, are not designed to face frontal collisions with small overlap. Despite the introduction of new regulations in Norway requiring frontal impact tests, these do not address the structural weaknesses observed in the aforementioned accidents. Current safety standards must be updated to include resistance testing for partial side impacts and to enhance protection in driver cabins.

Figure 1.7: Crash overlap in the three different accidents.

Accident 1:

Figure 1.8: Severe intrusion after the crash [1]

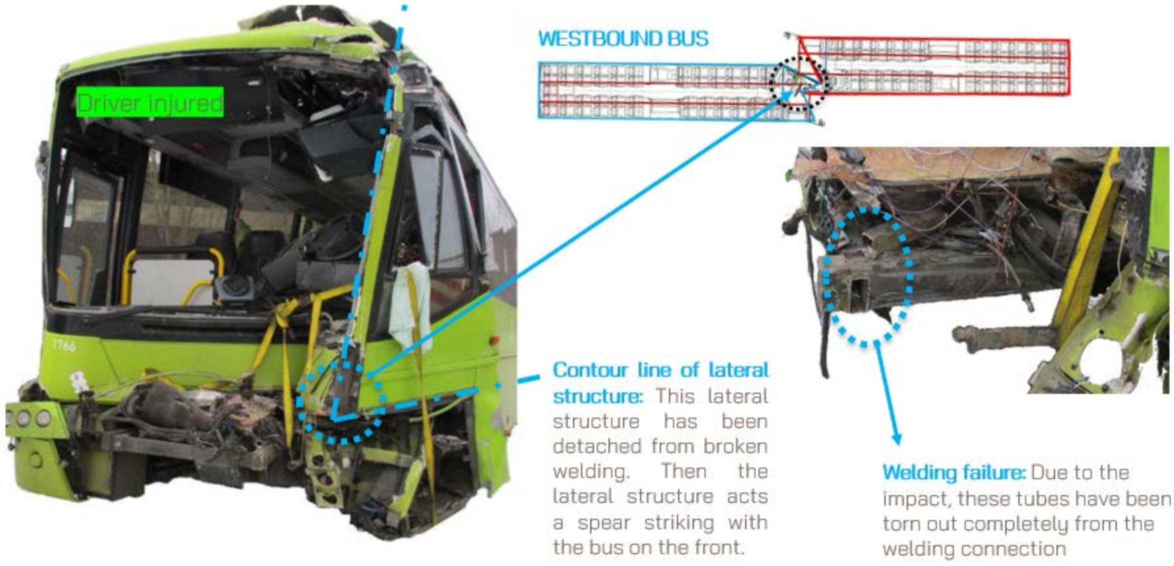

Figure 1.9: Structural status after crash [1]

Figure 1.10: Hard point in front area, towing hook [1]

ACCIDENT 2:

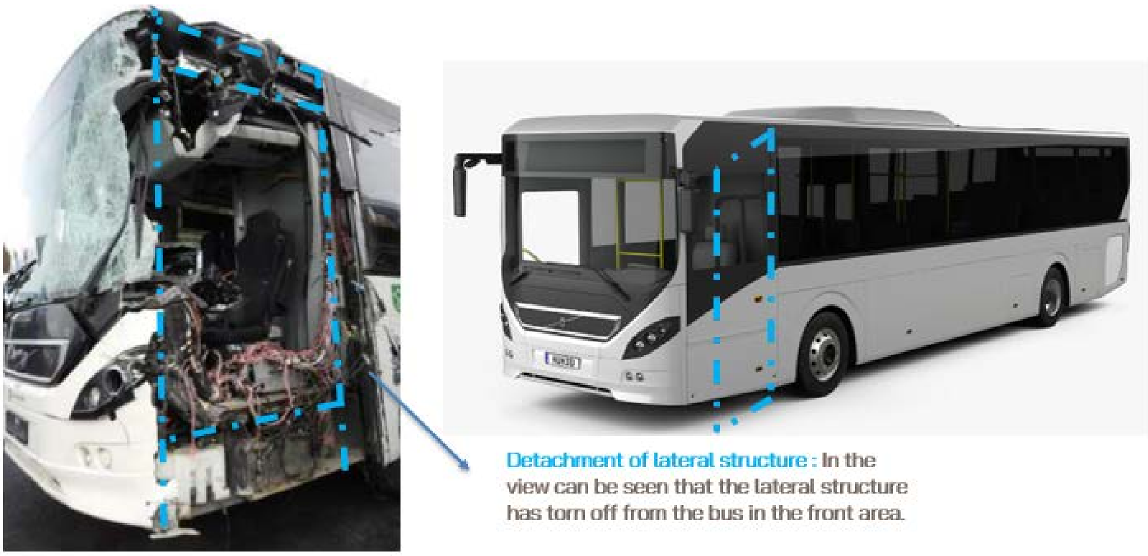

Figure 1.11: Structural status after the crash [2]

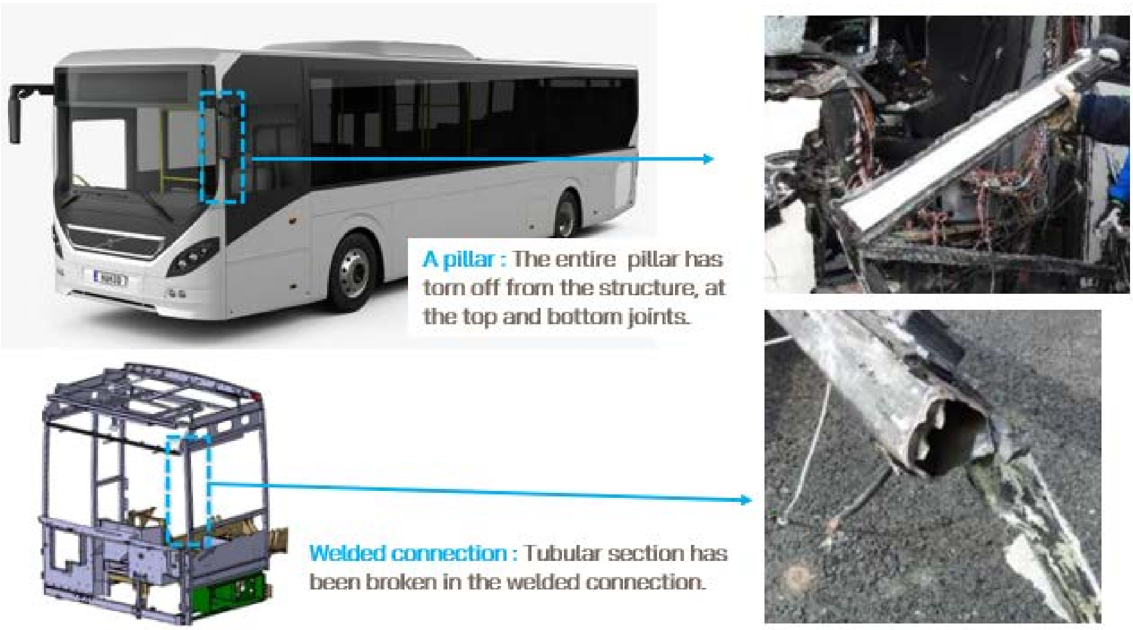

Figure 1.12: Structural status after the crash [2]

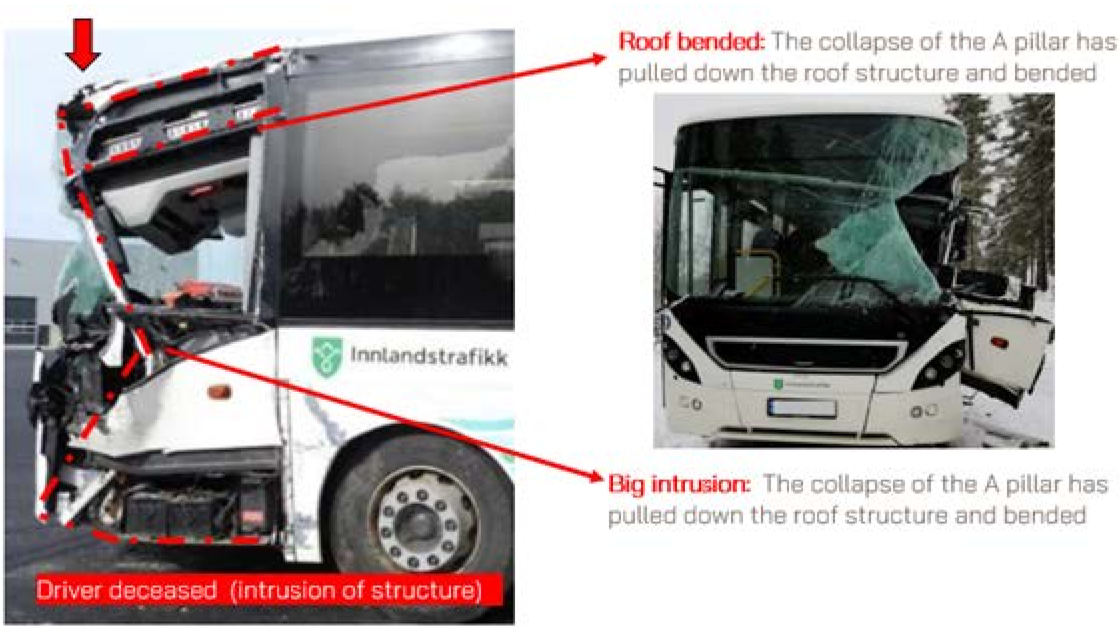

Figure 1.13: Structural status after the crash [2]

ACCIDENT 3:

Figure 1.14: Structural status after the crash [3]

Figure 1.15: Structural status after the crash [3]

1.4 Crash energy estimation in accidents

The impact energy of each of these three accidents was calculated based on the information given by the reports of the accidentology. No energy balance was considered for this estimation, so it would be necessary to extend these studies. Table 1.1 collects the information related to the accidents, revealing the corresponding bus masses, initial speeds from both parties, and total amount of energy produced during the crash.

Table 1.1: Crash data collected from the 3 accidents occurred in Norwegian roads.

	Nafstad	Tangen	Fredrikstad
Date	November 2017	March 2021	December 2022
Bus mass	Westbound: 13,060 kg	Westbound: 13,060 kg	Westbound: 13,060 kg
	Eastbound: 13,060 kg	Eastbound: 13,060 kg	Eastbound: 13,060 kg
Initial speed	Westbound: 34 km/h	Westbound: 42 km/h	Westbound: 32 km/h
	Eastbound: 34 km/h	Eastbound: 27 km/h	Eastbound: 35 km/h
Estimated crash energy produced	1,102 kJ	1,150 kJ	1,197 kJ

In the 3 accidents, the final crash speed between both buses is assumed to be 7.2 km/h (2 m/s). In addition, the mass ratio between buses is approximately 1, meaning that each bus absorbs half of the total amount of energy produced in the crash.

The level of energy produced in these three accident scenarios can be considered equivalent, considering the boundary conditions of all buses, summarized in the next image. The level is about 10 times the energy tolerance values prescribed in Regulation UN R29.03.

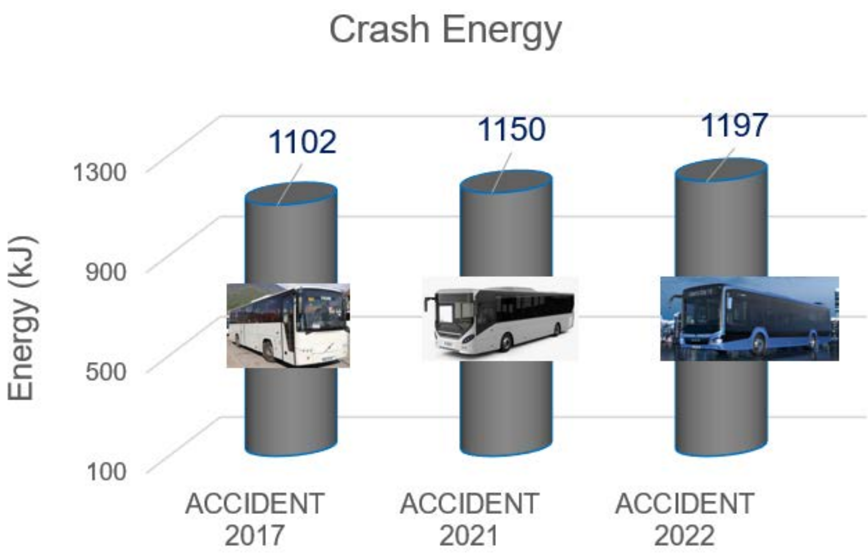

Figure 1.16: Crash energy produced in the 3 accidents.

1.5 Example of crash between bus and small vehicle

The compatibility between different types of vehicles is a crucial concern that requires attention. Addressing this issue is essential to decrease the number of deaths and injuries among passengers of public transport buses and those in vehicles involved in collisions with them, such as passenger cars.

In Table 1.2, crash energy produced for bus-to-car head-on collisions are presented, for different initial speeds prior to the crash. The mass ratio for the car with respect to the bus must be noted to be equal to 0.13.

Table 1.2: Energy evaluation in 3 different bus-car crash scenarios.

	BUS-CAR: 54 km/h	BUS-CAR: 30 km/h	BUS-CAR: 20 km/h
Mass	Bus: 10,360 kg	Bus: 10,360 kg	Bus: 10,360 kg
	Car: 1,333 kg	Car: 1,333 kg	Car: 1,333 kg
Initial and Final speed	Bus: 54 km/h; 7.2 km/h	Bus: 30 km/h; 7.2 km/h	Bus: 20 km/h; 7.2 km/h
	Car: 54 km/h; 7.2 km/h	Car: 30 km/h; 7.2 km/h	Car: 20 km/h; 7.2 km/h
Crash energy transmitted	Total: 1,292 kJ	Total: 788.6 kJ	Total: 171 kJ
	Bus: 1,124 kJ	Bus: 686 kJ	Bus: 148.7 kJ
	Car: 168 kJ	Car: 102 kJ	Car: 22.2 kJ

Figure 2 illustrates the ideal energy absorption capabilities for transit buses in collision scenarios. These vehicles should be engineered to dissipate kinetic energy across a broad spectrum, ranging from approximately 424 kJ when colliding with compact vehicles (mass around 1,333 kg) to as much as 2,000 kJ in impacts involving larger vehicles (mass approximately 12,000 kg). Conversely, smaller automobiles, such as the Dodge Neon (represented by the dotted blue line), would encounter significantly lower energy levels in similar collision scenarios. Such vehicles would need to manage kinetic energy ranging from 239 kJ in impacts with vehicles of comparable mass (1,333 kg) to 432 kJ when colliding with substantially larger vehicles (12,000 kg). This illustrates that smaller vehicles have a significant disadvantage when the collision partner is a heavier vehicle. Therefore, bus-to-passenger car crash compatibility differs from a bus-to-bus crash.

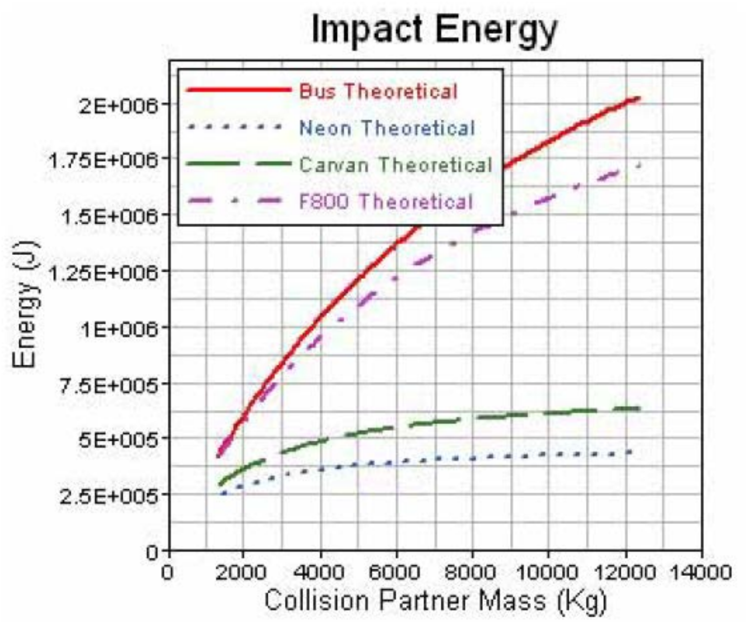

Figure 1.17: Theoretical impact energy depending on used vehicle and collision partner [5]

2 Bus Regulations for passive safety

Current bus regulations do not require mandatory front crash tests. Below, all applicable safety-related regulations are explained in more detail.

Information and statistics from accidents show that occupants in the first row, i.e. the driver and e.g. a guide, can be ejected through the front window, or affected by a severe intrusion in relatively low speed collision. Restraint systems connected to the seat provide better control of the movement of the seat's occupant in the event of a crash. This increases the probability that the driver remains conscious, can control the vehicle until it comes to a rest, and can facilitate evacuation. However, both limitations to the energy-absorbing capacity of the frontal area, and intruding objects through the front structure, remain a problem.

2.1 Strength of superstructure of large buses

The R66 regulation establishes a dynamic rollover test for bus structures. Such tests can be carried out physically, or through FEM computer simulation. The vehicle's framework must ensure sufficient strength to prevent compromising the interior free space both before and after the rollover test. No external vehicle components that are originally outside the occupant area may intrude into the interior occupant space during the test. The aim is to prevent external parts from invading the occupants' vital space during a rollover.

Additionally, no interior components, such as safety bars, pillars, or seats, should extend beyond the deformed structure. The theoretical contour of the deformed structure is determined sequentially by using the deformed positions of the pillars.

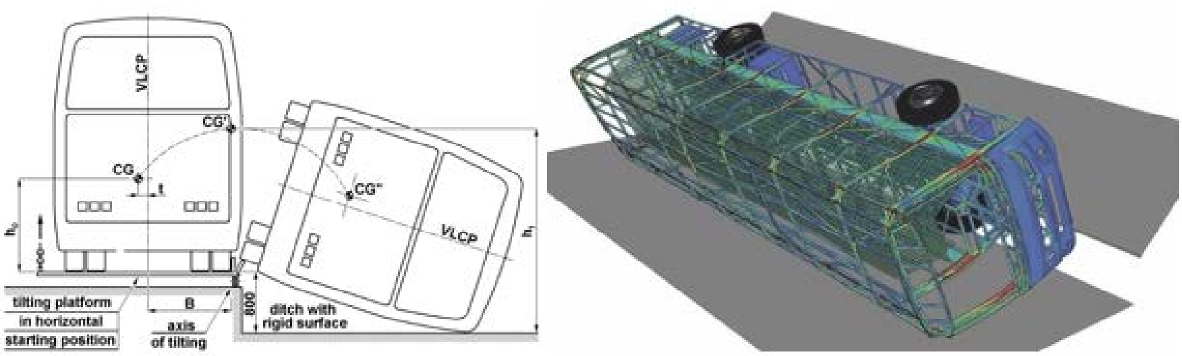

Figure 2.1: View of rollover test in buses (IDIADA).

An important point to analyze in this regulation is how the survival space is defined, as anything falling outside the limits it establishes is excluded from the standard and, therefore, not evaluated. The longitudinal boundaries are set as follows: 600 mm ahead of the R-point of the first seat, including the driver, and 200 mm behind the last seat. As a result, the first arch, which delimits the A-pillar, may be excluded. Consequently, it has been observed that designs tend to reinforce the second frame, usually located behind the driver's seat, which ends up having a cross-section several times larger than the rest of the arches.

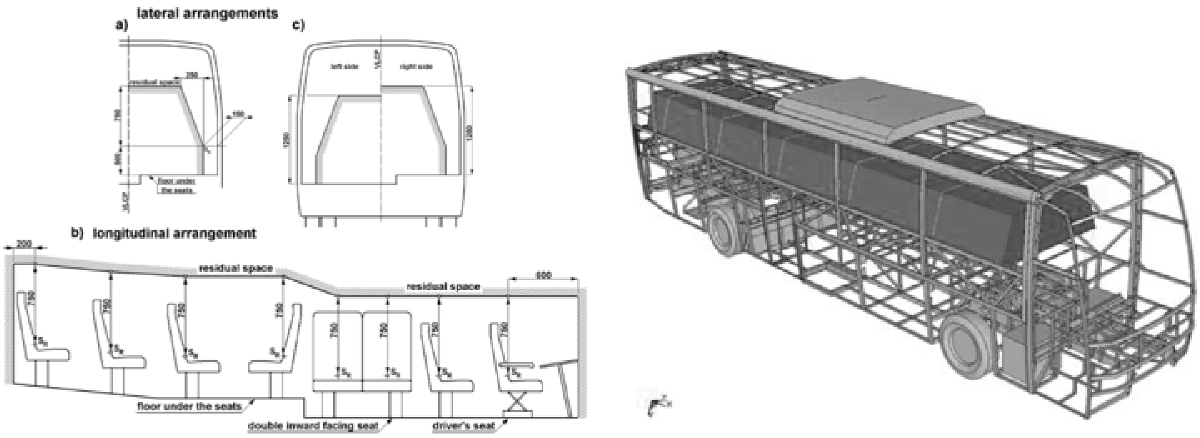

Figure 2.2: View of residual space for passengers (IDIADA).

The purpose of this test is to strengthen the arches of the superstructure, improving buses' performance in rollover scenarios. However, this is of limited relevance to the issue of small overlap frontal collisions. Despite the fact that test requirements do result in the reinforcement of the first arch in the driver's cabin, this primarily benefits the subsequent arches where the occupant survival space begins.

The rollover test uses a tilting platform to move the position of the bus to the unstable equilibrium, by rotating the vehicle by Angle α. Once the structure losses its equilibrium, this movement starts to accelerate, rotating along angle β, until it crashes against the ditch surface.

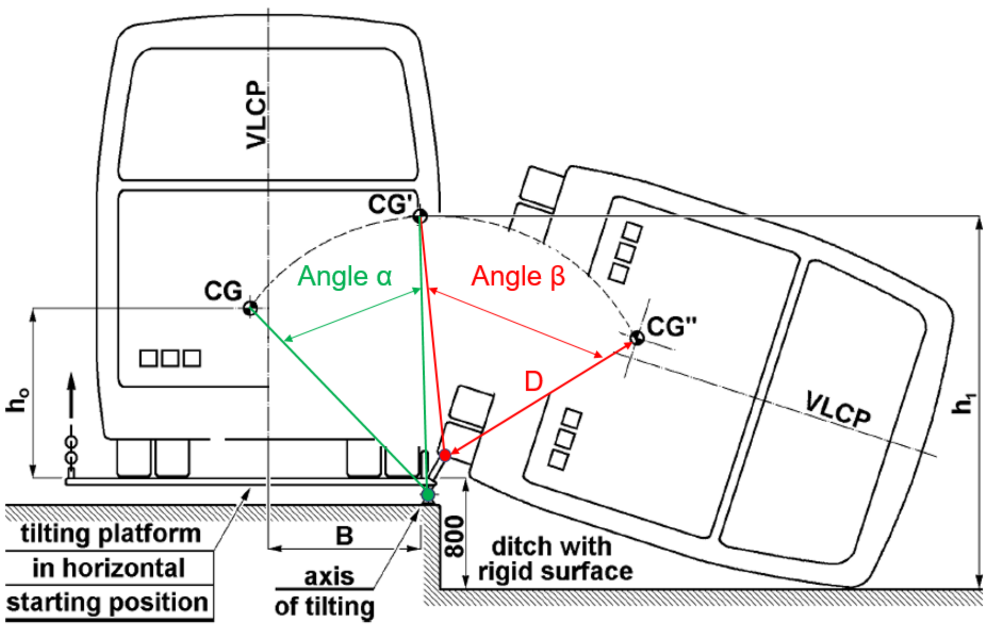

Figure 2.3: Angles of rotation. For equilibrium point and impact point (IDIADA).

Table 2.1: Energy study in rollover crash (IDIADA).

EXAMPLE OF ROLLOVER TEST APPLIED ON BUS	
Mass	Bus(kerb mass): 10,360 kg
	Passenger mass (x55p): 1,870kg
Final angular velocity just in the instant of crash with the ditch surface	2.4 rad/seg
	Rotational distance D=1.8m
Crash energy transmitted	Linear velocity: 4.32m/s
	Kinetic energy: 114.120 J

2.2 Evacuation UN R107

This regulation sets out the technical rules with respect to emergency doors. An effective measure would be a side window which, even broken, would remain in position and would act as a safety net to keep passengers within the bus' interior. At the same time, the design of coach corridors should enable rapid evacuation of bus occupants. This would require the possibility of ejecting windows easily after the coach comes to a rest, through the use of pirotechnica charges.

Safety of wheelchair users in coaches

A study assessing the safety of wheelchair users in coaches in comparison with travelers seated in conventional seats, fitted with headrests, has made various suggestions for modifications. The study found that the head and necks of wheelchair users were particularly vulnerable but that this could be addressed through the use of a head and back restraint. However, such a restraint should meet the requirements of UN R17 for strength and energy absorption and the wheelchair should fit well up against the head and back restraint for maximum benefit.

2.3 Structural related regulation (towing hook)

Regulation (EU) 1005/2010 establishes technical provisions for the approval of towing devices on motor vehicles, extending what was previously stated in Directive 77/389/EEC. It stipulates that all motor vehicles, including those in category M[3], must have a device enabling them to be towed. The technical requirement in this regard is that the towing hard point, and therefore the structure, must be capable of withstanding tensile and compressive forces equivalent to half of its maximum authorized mass.

Extrapolating this to buses, it creates a need to establish a point at the front of the chassis with resistant steel. However, this does not cover the entire front, nor the rigidify of the frame.

2.4 R80 Strength of seats and their anchorages on buses

Regulation UN R80.04 specifies technical parameters for evaluating the strength and safety of seats and their attachments in buses. It establishes geometric and functional conditions such as a minimum height of 1 meter and the requirement to ensure a lock on any movable element it includes. In any case, the seat must ensure its structural integrity, the cohesion of all its accessories,

[3] Category M is: "Motor vehicles with at least four wheels, designed and constructed for the carriage of passengers", according to the mentioned directive.

and its attachment to the anchorages. It must also not present sharp edges or pointed elements after the tests.

R80 regulation includes two types of tests: the first relates to passenger seats, where the impact of an occupant on the seatback is evaluated (Figure 2.4), and a second test involves traction on the seat, where the attachments must withstand the force (Figure 2.5).

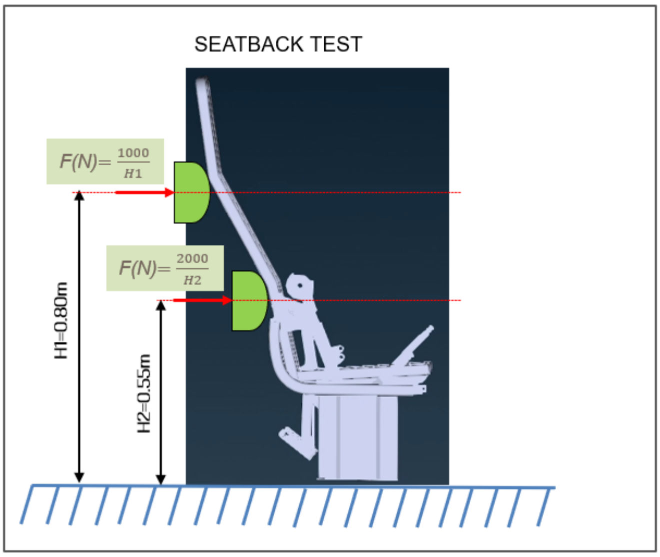

Figure 2.4: Example of seatback test (IDIADA).

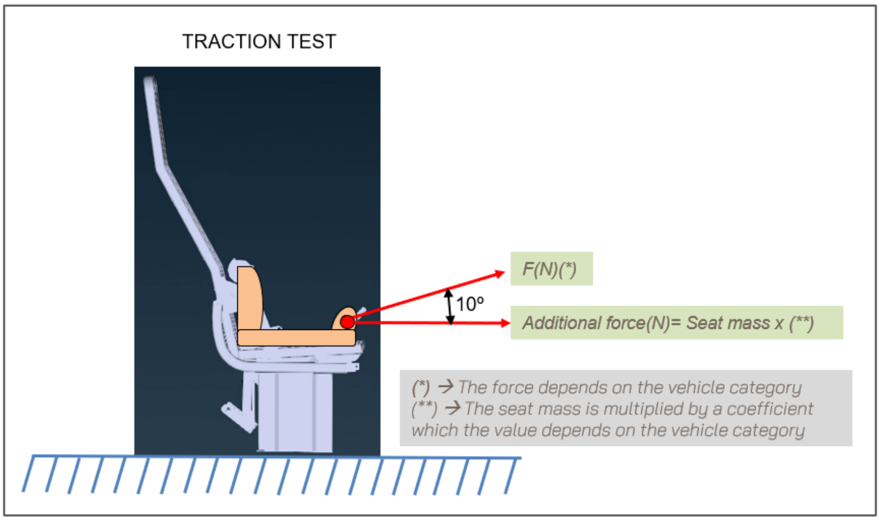

Figure 2.5: Example of a traction test of a 2 point seat belt anchorage (IDIADA)

If a solution is implemented that affects the seat design for protection in the event of an accident, these resistance parameters must be respected. Functional issues related to the driver's tasks, such as the ability to collect fares, limiting the maximum height, seat stability, or visibility ergonomics of the road, must also be considered.

3 Truck regulations

3.1 R17 Seat, head restraints and seat anchorages strength

The UN R17.11 regulation includes generalized requirements for the approval of seats, with regards to their strength and standards. This applies to the seats of M2 and M3 class vehicles not covered by UN R80. The regulation includes pendulum impact tests on headrests to ensure they are sufficiently padded and free of sharp edges. A second test involves mounting the seat on a sled to verify the anchorages' resistance to a 50 km/h impact. Finally, seat backs must withstand impacts from luggage objects without compromising their structural integrity.

3.2 R29.03 protection of the occupants of the cab of a commercial vehicle

Regulation R29.03 defines the test procedures for assessing the structural resistance of cabins in heavy commercial vehicles of type N (e.g. trucks). The primary objective is to ensure occupant safety in accidents such as rollovers, frontal collisions, or lateral impacts.

The regulation specifies tests to verify that the cabin structure can absorb and distribute forces generated during a crash, avoiding severe collapses. Additionally, it requires sufficient survival space inside the cabin to protect the driver and passengers. For this assessment, a test manikin is placed on the driver's seat to evaluate cabin deformation.

The evaluation consists of three different tests designed to encompass all types of accidents a truck cabin may face:

Test A: Frontal Impact

A pendulum weighing 1,500 kg strikes 50 mm below the R-point of the driver's seat. The impactor is a flat plate with a total width of 2,500 mm and a height of 800 mm, covering the entire cabin width. The total energy for the dynamic test is 55 kJ (for vehicles over 7.5 tons).

Test B: A-Pillar Test. Rollover 90°

This test assesses the resistance of the cabin's A-pillars. The impactor is a cylinder with a total width of 2,500 mm and a diameter of 600 mm, also covering the entire cabin width. The impact occurs directly on the windshield, with an energy of 29.5 kJ.

Test C: Lateral 180° rollover.

Analog to R66 for buses, with a similar purpose but a different way to evaluate the cabin's resistance in a side rollover. It involves a lateral flat impact with an energy of 17.6 kJ at a 20° angle, weakening the structure laterally. A static load of 98 kN is then applied, corresponding to an estimated maximum authorized mass per cabin axle(s).

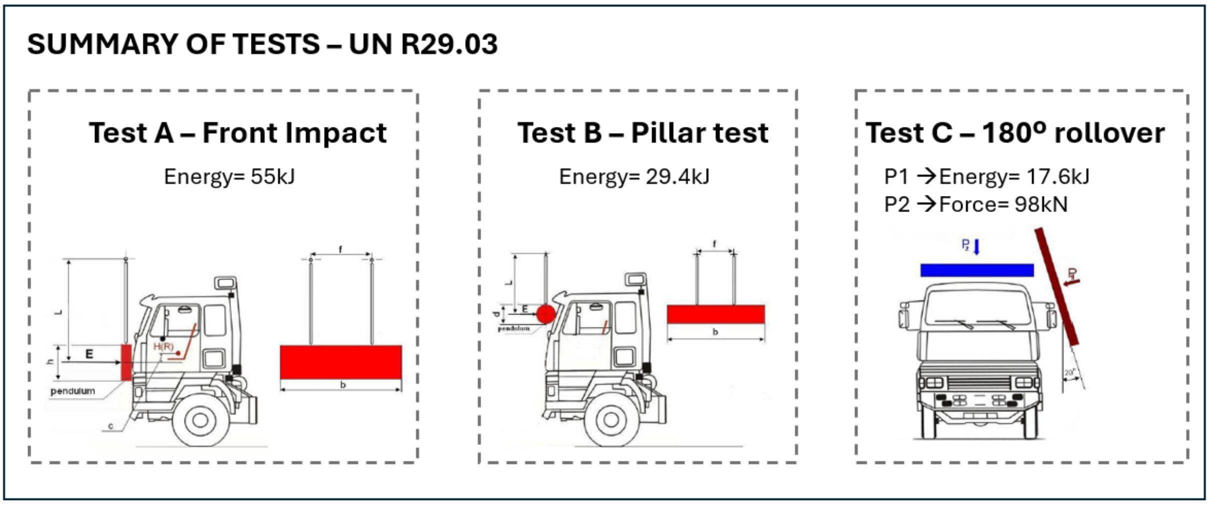

Figure 3.1: Tests required in UN R29.03 (IDIADA)

3.3 R93.00 Front Underrun Protection Devices

The UN R93.00 regulation sets the technical requirements for front underrun protection devices in heavy commercial vehicles, such as trucks in categories N2 and N3 (N2: 3,5-12 tonnes, N3: >12 tonnes). Its main goal is to prevent smaller vehicles from sliding under the truck in frontal collisions, reducing the risk of severe or fatal injuries to the occupants of these vehicles.

The regulation mandates a beam-like structure strategically positioned to absorb the energy of a passenger car in the event of a frontal crash between a car and a truck. This underrun protection device undergoes tests at various points by applying loads. At point P1, a load of half the vehicle's mass up to a maximum of 80 kN is applied, while at point P2, the test applies the vehicle's full mass up to a maximum of 160 kN.

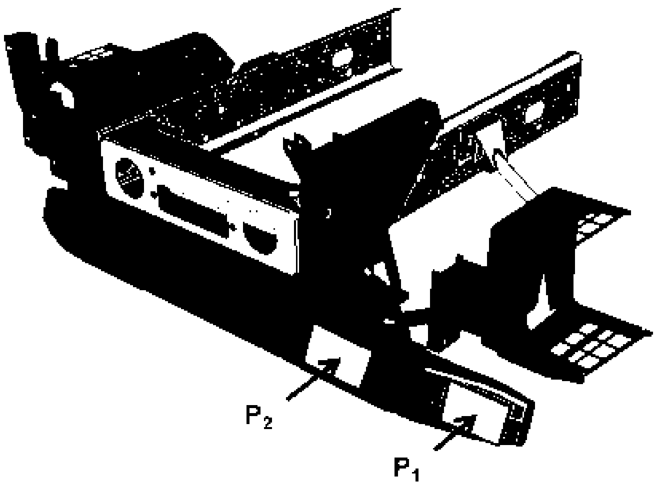

Figure 3.2: View of front underrun protection device (IDIADA).

This regulation is highly effective for compatibility with light vehicles as it shifts the point of impact and deformation energy to an area where the passive safety mechanisms of light vehicles can function. However, its effectiveness is significantly limited in other types of collisions, and it does not provide compatibility in impacts with larger vehicles, such as another truck or a bus.

3.4 R58 Rear Underrun Protection Devices

The UN R58.03 regulation shares the same objective as R93.00: to prevent light vehicles from underrunning trucks, specifically addressing rear-end collisions. Similar to its frontal counterpart, it defines specific points on the beam where it must withstand the following loads:

- **P1**: 12% of the vehicle's gross mass, up to a maximum of 100 kN.
- **P2**: 50% of the vehicle's gross mass, up to a maximum of 180 kN.
- **P3**: 12% of the vehicle's gross mass, up to a maximum of 100 kN.

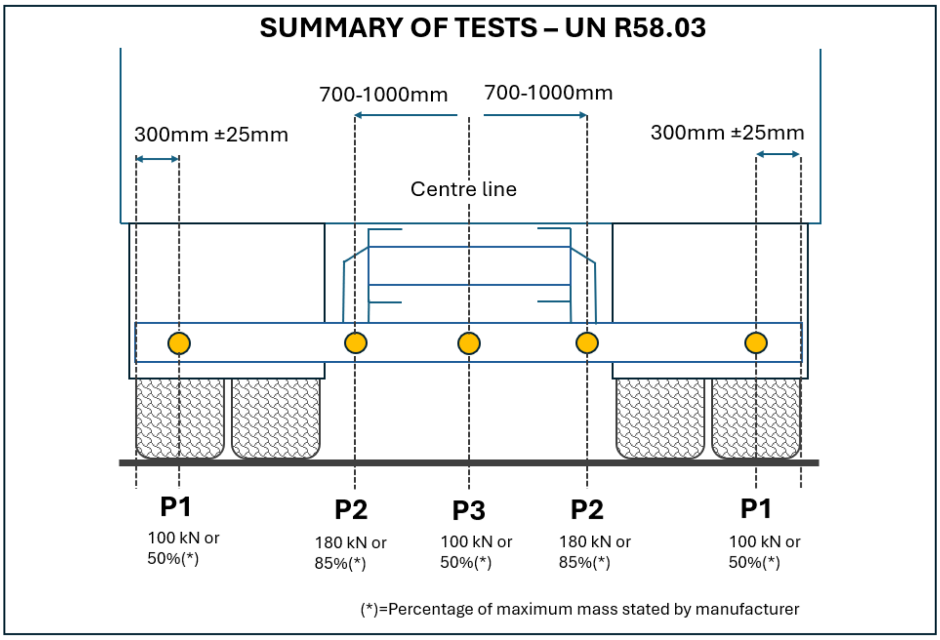

Figure 3.3: View of different load location applied to rear underrun protection.

4 Applicability of truck regulations in buses

In figure 4, energy comparisons between the different frontal impact test regulations affecting both light vehicles and commercial vehicles are presented. The test that most closely resembles the case under consideration—a frontal offset collision between two vehicles—is the mandatory UN R94 regulation, which establishes an impact speed of 56 km/h. The energy requirement increases with the test mass.

An energy gap becomes evident when moving to regulations for commercial vehicles (>3,500 kg). Impact energies not only fail to increase for heavier vehicles, but the requirements are also significantly less restrictive. The energy values are far from the calculated estimates for bus-to-bus collisions, approximately 110 kJ, or bus-to-car collisions, around 168 kJ, when using speeds similar to R94. This clearly shows that the current testing landscape is not sufficient.

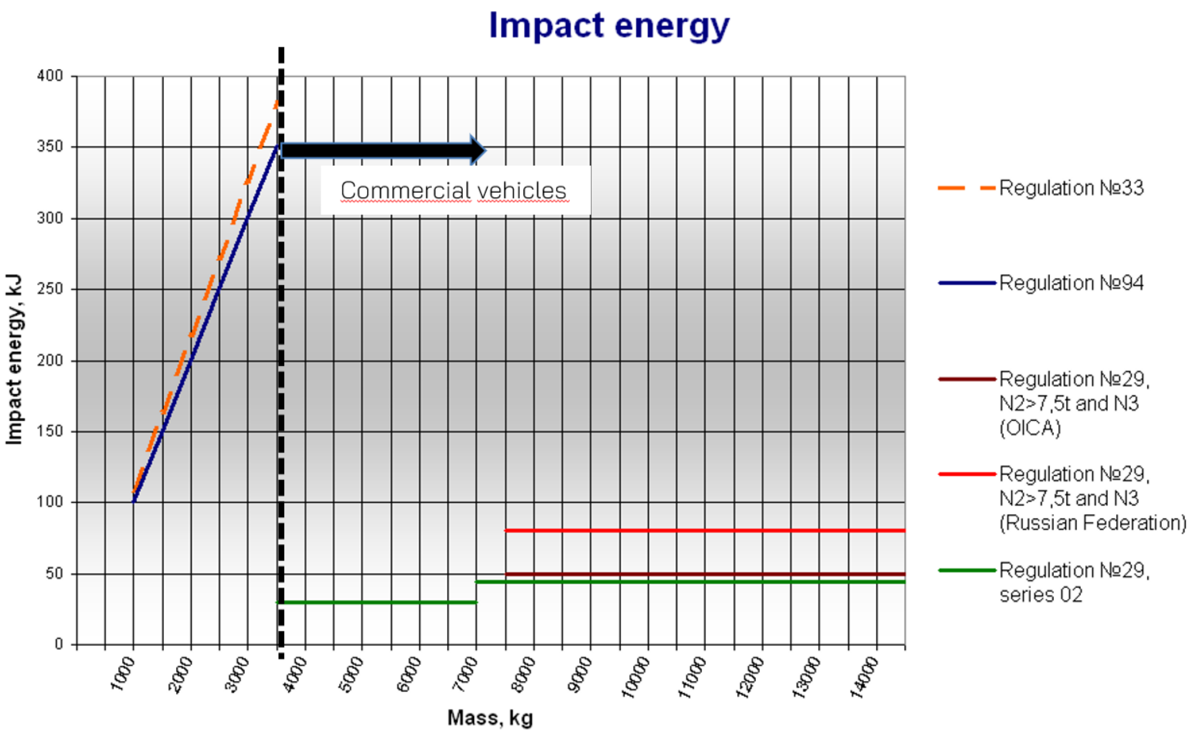

Figure 4.1: Energy balance between different vehicle categories [1]

5 Proposal for improvements

5.1 Improvement of crash compatibility

A comprehensive study of three bus-involved accidents has revealed significant compatibility issues in collisions between buses and other vehicles. These findings highlight critical areas for improvement in vehicle design and safety regulations.

The primary problem observed is the inadequate energy absorption by vehicle structures during collisions. In the analysed cases, the bus structures tend to deform and open up upon impact, leading to severe intrusions into the colliding vehicle. What's particularly alarming is the disproportionate severity of both structural damage and personal injuries, especially considering the relatively low impact speeds in these incidents.

A common factor in all three accidents was the small overlap nature of the impacts. This scenario concentrates the impact energy in a very limited area of the vehicle's front, magnifying the destructive forces and exacerbating the damage caused. The focused energy transfer in these small-overlap collisions poses a significant challenge to current vehicle design paradigms.

One of the most critical issues identified is the behaviour of the bus's frontal structure during impact. The transversal profile, which serves as the sole structural element connecting the sides at the front of the bus, detaches during the collision. This structural failure leaves the edge of the side panel unrestrained, effectively turning it into a 'battering ram'. The resistance and rigidity of this now-detached side panel cause it to penetrate the opposing vehicle with devastating consequences, resulting in severe damage and increased risk of injury to occupants.

To address these critical safety concerns, several potential solutions can be considered to improve the crash compatibility.

1. **Enhanced Structural Integrity**: Developing more robust connections between the transverse profile and the side panels of buses is crucial. This could involve redesigning the frontal structure to maintain its integrity during impacts, preventing the 'battering ram' effect observed in the studied accidents.
2. **Energy Absorption Zones**: Incorporating dedicated energy absorption zones in the front structure of buses could help manage impact forces more effectively. These zones should be designed to deform progressively, absorbing energy while maintaining the overall structural integrity of the vehicle.
3. **Small Overlap Impact Testing:** Introducing mandatory small overlap impact testing for buses, similar to tests now common for passenger cars, could drive improvements in design to better handle these challenging impact scenarios.
4. **Advanced Materials:** Exploring the use of advanced, energy-absorbing materials in bus construction could provide better protection without significantly increasing vehicle weight.
5. **Compatibility Design Standards:** Developing specific standards for vehicle compatibility between buses and smaller vehicles could lead to designs that interact more safely during collisions.
6. **Mandatory Implementation of Regulation UN R93.00**: The United Nations Economic Commission for Europe Regulation No. 93 addresses front underrun protection on heavy goods vehicles. While primarily designed for trucks, adapting and mandating this regulation for buses could significantly improve their compatibility with smaller vehicles in frontal collisions. The regulation UN R93.00 standard requires the installation of a front underrun

protection device, which could help distribute impact forces more evenly and prevent smaller vehicles from under-riding the bus in a collision.

7. **Integration with Towing Hook regulation:** Combining requirements from UN R93.00 with existing towing hook regulation (EU R1005/2010) could provide a dual-purpose solution. By designing a robust front structure that serves both as an underrun protection device and a standardized towing point, we could enhance both safety and utility. This integrated approach would ensure that the frontal structure of buses is strengthened without compromising serviceability.

Implementing these solutions would require a coordinated effort from vehicle manufacturers, regulatory bodies, and safety organizations. By mandating the R93.00 standard for buses, combined with enhanced towing hook regulations and the additional measures suggested, we could significantly improve the safety outcomes in bus-involved collisions.

The goal is to create bus structures that not only protect their occupants but also minimize damage and injury risk to occupants of other vehicles involved in collisions. This holistic approach to vehicle safety design is essential as we strive to reduce the severity of road accidents and improve overall traffic safety.

Further research and real-world testing will be crucial in refining these solutions and ensuring their effectiveness across a wide range of collision scenarios. By addressing these compatibility issues, we can work towards a future where the severity of bus-involved accidents is significantly reduced, including at lower impact speeds, thereby enhancing road safety for all vehicle occupants.

5.2 The position of the driver

The position of the driver is very important in terms of severity in accidents. Taking the example of the driver position in urban buses and coaches, we can observe significant differences.

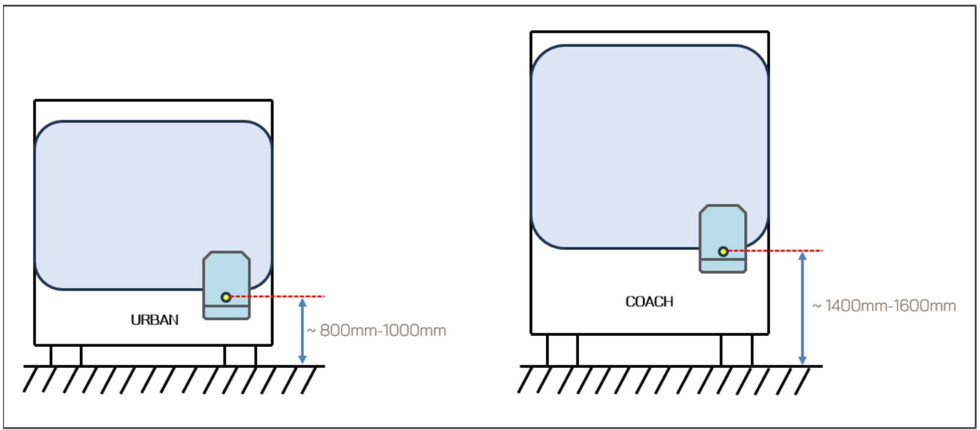

Figure 5.1: Driver seat height comparison, between low floor bus and a coach (IDIADA).

In urban buses, the height of the driver position is approximately 800mm to 1000 mm, while in coach buses the driver position is approximately 1400mm-1600mm high.

In the case of urban buses, it would be possible to raise the position of the driver slightly, but ergonomics would have to be checked in order to be able to carry out passenger control functions, such as collecting admission. In any case, this increase in height would be very small. Positioning the driver further back would be even more complicated, since that would mean movement restrictions due to the small distance from the seat to the front wheelarch position. In some specific cases it would mean eliminating the capacity of a row of seats, which would make the bus less competitive in the market.

5.3 Reinforcements in the structure

In the three studied Norwegian bus accidents, one can see that bus lateral side structures are totally intruding opposite buses, by literally 'cutting' the structure, like a knife. The level of severity for this type of accident is extremely high, so structural design, reinforcements and materials should be focused on avoiding this situation as much as possible to improve crash compatibility. Structural reinforcements should be focused on the driver side and avoid mainly two things: One is to prevent the transversal tubes in the front low area to be detached, and the second to avoid the collapse of the connection hinges 1, 2 and 3 to be close to the driver (cf. Figure 29). The strategy could be to use a 'semi-cage' open structure, protecting the lower area, as well as providing a better connection with the roof.

In addition, dealing with the amount of energy in collisions is also an important point to solve. The reality of the Norwegian bus accident examples is that energy levels are much higher than the energy level proposed by UN R29.03 (type-A), which applies 55kJ in the whole width of front structure. The definition of a specific test or tests to evaluate bus safety in more realistic conditions would be necessary.

As the present study is a desk study, it is necessary to implement a deeper study based on simulations and/or testing to validate our recommendations and suggestions. It is important to execute a set of simulations considering different overlaps and angles to catch the worst-case scenario, and from this point to define proper tests to be applied.

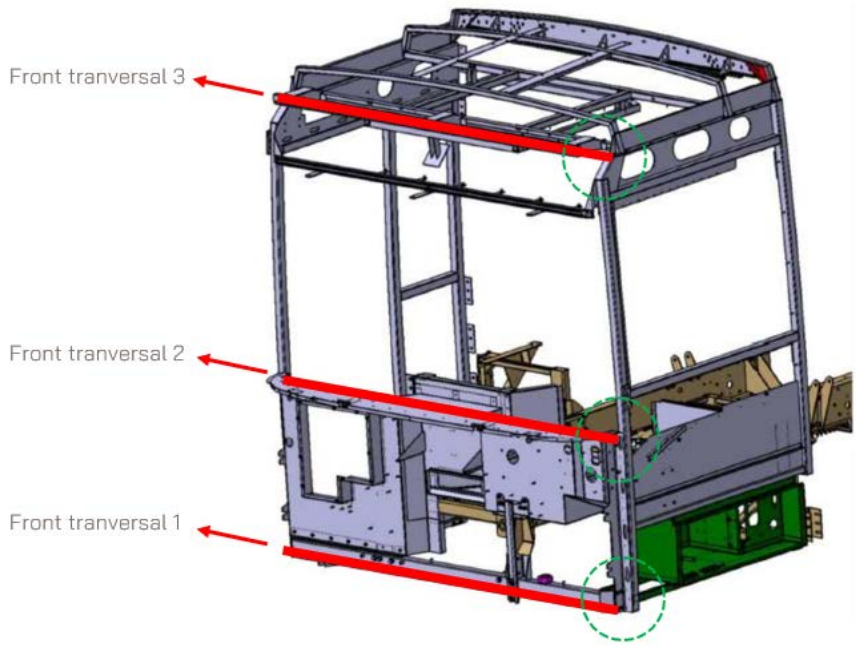

Figure 5.2: Reinforcement applied in the front transversal profiles (IDIADA).

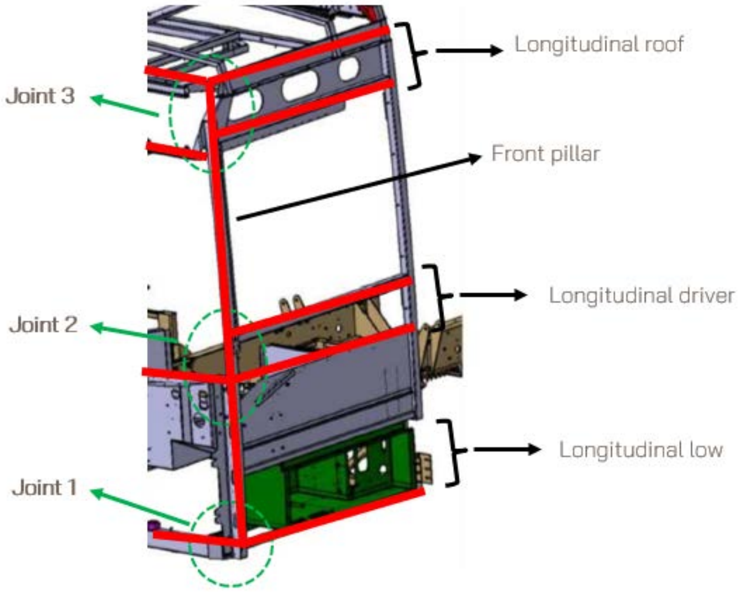

Figure 5.3: Reinforcements applied in the joint connections (IDIADA).

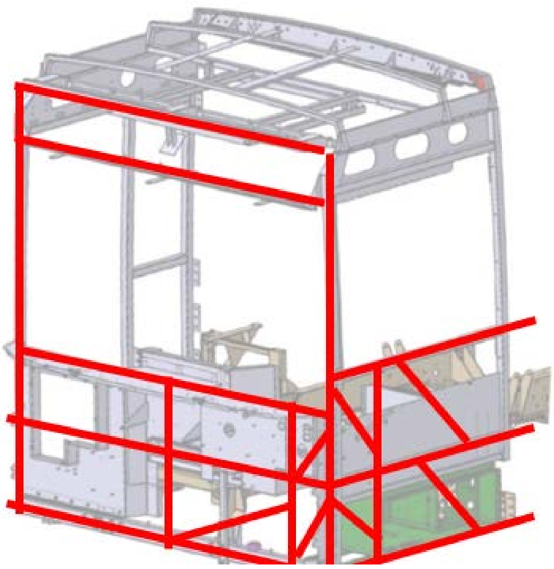

Figure 5.4: Reinforcement proposed in lower front-lateral connection (IDIADA).

5.4 Reinforcement of front grill and floor

In the realm of bus crash safety, one critical area of concern is the behaviour of the frontal structure during collision events. Current designs often result in the front of the bus transforming into a hazardous 'lance' or 'battering ram' upon impact. This transformation has lethal consequences, particularly for the drivers involved in such collisions.

The primary issue lies in the lower frontal structure of buses, which currently lack adequate connections and reinforcement. During a high-impact crash, this weakness allows the front end to collapse and protrude forward, effectively creating a penetrating force that significantly increases the severity of the collision. This phenomenon not only endangers the bus occupants but poses an extreme threat to the occupants of other vehicles involved in the crash, especially those in smaller passenger cars.

To mitigate this risk, it is imperative that we focus on improving the connections within the lower frontal structure of buses. Enhanced structural integrity in this area would help maintain the bus’s shape during a collision, preventing the formation of the dangerous ‘lance" effect’. This improvement would involve reinforcing key points of the frontal frame and implementing more robust joining techniques to ensure the structure remains cohesive under impact forces.

One promising approach to addressing this issue involves leveraging the inherent strength of the towing hook mount point, mandatory for buses under regulation EU R1005/2010. The towing hook point area, designed to withstand significant forces, could serve as the starting point to extend the frontal structure reinforcement and to be used as the front underrun protection, aiming to reduce the risk of smaller vehicles under-riding bus structures in the event of frontal collisions.

Currently, the front underrun protection system is only mandatory for trucks, not buses. In this case, our proposal is to extend this requirement to buses, to combine the requirements of R1005/2010 and UN R93.00, and to develop a frontal structure to effectively increase the crumple zone and energy absorption capabilities of the bus.

This extended structure would serve multiple purposes:

1. It would prevent fatalities caused by the intrusion of the lateral panel of the collision partner into the bus driver’s cabin by providing a controlled deformation zone.
2. It would offer better protection to the bus driver and passengers by managing impact forces more effectively.
3. Most importantly, it would significantly enhance the safety of occupants in smaller vehicles involved in collisions with buses.

Implementing such a design would require careful engineering to balance the need for increased frontal protection with considerations of weight, aerodynamics, and overall vehicle performance. However, the potential benefits in terms of improved safety outcomes make this a worthwhile endeavour.

Summarizing, by focusing on strengthening the lower frontal connections, extending the front structure from the towing hook point (EU R1005/2010), and meeting R93.00 requirements, the lethality of bus-involved collisions can be significantly reduced. This approach not only protects bus occupants, but also offers vital protection to other road users, particularly those in smaller vehicles who are most vulnerable in such crash scenarios.

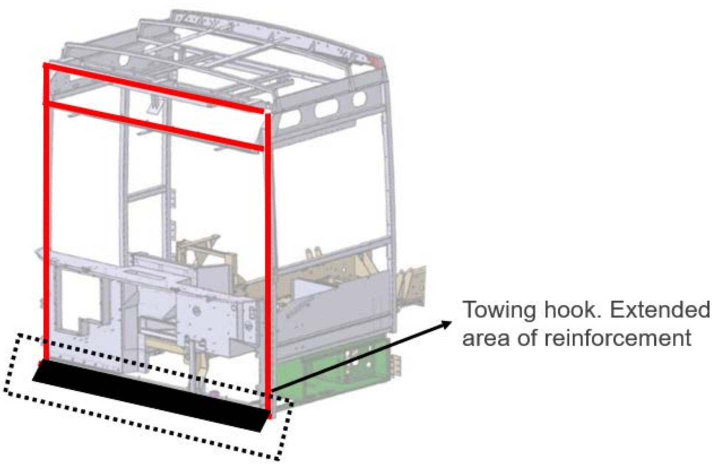

Figure 5.5: Schematic example of reinforcement in lower front (IDIADA).

5.5 Reinforcement of the roof

Looking at the three discussed Norwegian bus accidents, upper roof connections were detached from the buses' lateral structures. From the accident at Tangen (2021), we could additionally observe that the roof structure was bended down due to the big deformation occurring during the crash. The stiffness of the roof structure and the quality of the connection with the front pillar is assumed to have a big impact in the safety results during the crash. Our recommendation is to increase the strength of the roof connection with the first arch located in the windscreen, and also the connection with the second safety arch, just behind the driver. In addition, the use of reinforcement brackets for the tube connection, and the application of a good weld location strategy, would help to keep the big deformations out from welded areas so the risk of detachment of connections could be reduced significantly.

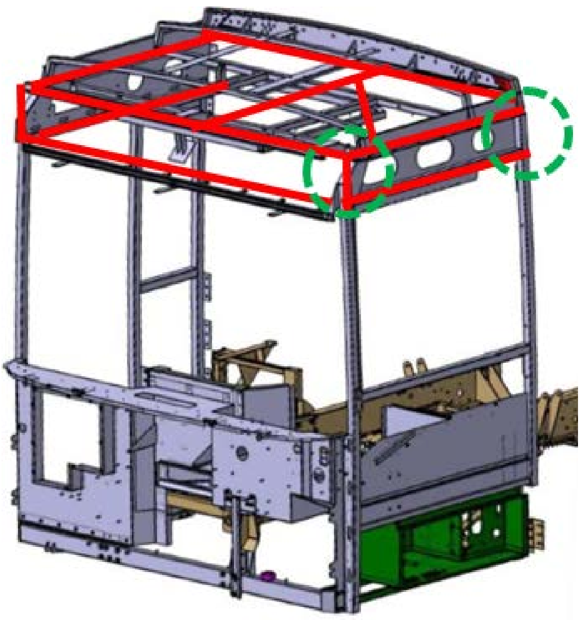

Figure 5.6: View of reinforcement proposal for roof (IDIADA).

6 Next steps

Following this desk study, we consider that it would be necessary to continue with a deeper understanding of how structures work under crash conditions. The use of simulations by using the current bus models in realistic conditions will allow the validation or rebuttal of our assumptions and will strengthen focus on finding the most effective ways of improving safety.

We therefore propose to follow-up our current study with the following additional work:

- Part 1: Sensitivity analyses with different accident configuration (Bus-to-Bus):

In this part, several simulations should be performed, adjusting contact overlap, angle and energy at the moment of contact between vehicles. A main objective would be to identify what types of bus-to-bus crashes would constitute the 'worst possible cases' and to analyze the reasons and drivers for this.

- Part 2: Definition of the most representative test (Impactor-to-Bus):

Main objectives in this part would be to identify which impactor and what configuration represent(s) the most realistic conditions and to define the best and most representative physical tests. Here, the impactor should be adjusted against the bus in terms of overlap, angle and energy. A matrix with combinations of all these factors should be set up, followed by simulations.

- Part 3: Virtual test including countermeasures (Improvements):

Some selected simulations from Parts 1 and 2 will be repeated after implementing the countermeasures. The objective will be to identify what structural aspects are more or less sensitive and to validate the general trends of the designs meant for improving safety.

7 Bibliography

[1] Accident report. Report on head-on collision between two uses on county road FV 450, at Nafstad in Ullensaker on 17 November. Accident investigation board Norway.

[2] Accident report. Head-on collision between two buses on the fv. 222 road at Tangen in Stange Municipality, March 11th , 2021.

[3] Accident report. Head-on collision between two buses on the Rv 110 road in Fredrickstad on December 2022. Norwegian Safety Investigation Authority.

[4] Proposed changes to the EEC UN Regulations 29, GRSP-INF-CS-14e, UNECE.

[5] Mass transit Bus-Vehicle compatibility evaluations during frontal and rear collissions, G.Olivares, V.Yadav, *National Institute for aviation research (USA), Paper nº 07-0477*

[6] https://road-safety.transport.ec.europa.eu/eu-road-safety-policy/priorities/safe-vehicles/archive/safety-design-needs/buses-and-coaches_en

[7] https://road-safety.transport.ec.europa.eu/eu-road-safety-policy/priorities/safe-vehicles/archive_en

[8] https://road-safety.transport.ec.europa.eu/sites/default/files/2024-03/collision_matrix_urban_2024_update.png

[9] https://road-safety.transport.ec.europa.eu/sites/default/files/2024-03/collision_matrix_2024_update.png

[10] https://unece.org/2nd-meeting-10

[11] https://unece.org/DAM/trans/doc/2006/wp29grsg/ECE-TRANS-WP29-GRSG-90-inf31e.pdf

Exhibits

Exhibit 1. Specification from the Institute of Transport Economics

Technical Study of collision protection for bus drivers

The fourth aim of the study is to conduct a technical study of collision protection for bus drivers, and develop new solution trends for collision protection. The technical study has been conducted by the Spanish company IDIADA, and it has been headed by Manuel Laso. The first basis for the technical study was formed by the three NSIA in-depth reports focusing on the 2017, 2021 and 2022 bus accidents in Norway. One of these reports has been translated by the authors, the two other reports were available in English versions. IDIADA performed a desk study, without including any simulation activity, which used the participation of several experts in structural design, structural safety and occupant safety.

The second basis of the technical study was a problem description provided by TØI. The problem description was based on the conclusions and information in the three NSIA reports and interviews with experts. It was also validated, nuanced and expanded through communication with representatives from several parties, e.g. the Norwegian National Public Roads Administration, Public Transport Norway, Ruter, bus driver unions like YTF and Fellesforbundet, Fagforbundet, employer organizations like NHO transport, the Norwegian Safety Investigation Authority, Bussmagasinet, and many more. Several iterations of the problem description were submitted to these parties, and some of the parties provided new points and/or nuances.

The problem description was comprised of the following points:

- The bus needs something in the front which rejects and absorbs impact.
- The most relevant things to consider are R29 and R93.00. These are taken from trucks.
- Differences between trucks and buses must be taken into account, and the most important will be listed below.
    - Driver cabin safety/ protection. A definition of the driver cabin is lacking in bus vs. truck. It is not considered as a separate unit.
    - The superstructure or chassis of the truck is more solid. Thus, it probably provides a more solid base for frontal protection devices like R29 and R93.00.
    - Trucks are based on large self-containing structures.
    - Buses are built on smaller and lighter structures. R93.00 (truck's bumper) requires a solid base to reject forces.
    - The frontal axle is placed differently on trucks and buses. Thus, for buses, there is more room, before you «hit something hard» in a crash. (40-50 cm vs. 200 cm).
    - Buses do not have a drivers' door on the left side. In collisions, the front left side of the bus (2-meter structure) works as a «hinge» from the point of the frontal axle.
    - The front left side of the bus (cf. ECE R66) is built in a way which is optimal to prevent collapse in case of rollover.
    - Should the driver be placed differently?
    - Electric buses probably come with stronger structures.

- Systematic point to take in: Please discuss the considerations/schemes you develop into specific considerations/recommendations for Class 1, 2, 3 buses.
- Systematic points to take in: A) How are other road users' (passive, active) safety affected by the suggested solutions? B) How are the passengers' (passive, active) safety affected by the suggested solutions.

Extra questions that were taken into consideration

- Is it relevant to change the front of the bus into a 'beak design', to include a pedestrian friendly deformation zone?
- Before a crash, the bus front tends to tilt down, as the bus brakes hard. How does that affect the suggested solutions?
- How much difference can an airbag make for the bus driver?
- What about moving the driver's seat to a more centered position (away from the left side)?
- What about positioning the driver higher in the front of the bus?
- What about constructing a 'driver-seat section' which moves backwards in case of a crash? (Yutong is now working with this, we have seen images).
- Is it possible to construct a 'cage' with beams around the driver, which has a deformation zone behind the driver.
- How much difference will it make to strengthen the A-pillar on the left side, and to strengthen the structure in front of the driver in general?
- How important are measures aimed at preventing accidents (e.g. ADAS), vs. measures to reduce injury when accidents happen (e.g. collision protection).
- Consider the possibilities for a simulation study, as a continuation of the project.

Additional points based on stakeholder communication and validation:

- The left corner and the area in front of the driver should be strengthened. This approach would allow for reinforcing the driver's compartment while simultaneously incorporating a deformation/ crumple zone behind the driver. This way, the driver's area remains protected, but impact energy still has a place to dissipate effectively. It is a good idea to have a system where, in the event of a collision, the driver is pushed 15 cm backward, and the steering wheel is moved forward.
- '...Positioning the driver higher...', you could elaborate on the potential benefit of utilizing the space beneath the driver for reinforced crash safety features or a crumple zone. Regardless, it would be advantageous for the driver to be positioned higher in collisions (particularly with passenger cars), as this can enhance their safety.
- Under point: '...to strengthen the A-pillar...', the area in front of the driver and the entire sidewall must be significantly reinforced (with larger dimensions or higher-strength materials). This applies to the A- and B-pillars, as well as the attachment points of the sidewall to the rest of the structure, to prevent the sidewall from acting as though it is hinged. If you could provide more specific details on this aspect, we would greatly appreciate it.
- R29 is divided into three different elements, where we have adopted the A part for buses, featuring a pendulum test at the front. An alternative could be to use a similar pendulum test but angled diagonally toward the driver's area in a bus. This would provide a simple way to test the strength of the A-pillar and the area around the driver. It is not an optimal solution but is significantly better than the current R29 test directly at the front's center.

- R93.00 is solely intended to prevent passenger cars from sliding under a large vehicle in the event of a collision. While R93.00 could result in reinforcement, it would likely have very limited impact on driver safety. It is crucial to consider whether this could have the opposite effect, where a car that doesn't slide under a bus instead rises up and intrudes into the driver's compartment. This was partially the case in the Sørås accident in June 2020.
- Should some ideas also be drawn from passenger cars/vans, particularly regarding how the structure of a van with a flat front is designed for crash safety? Perhaps there are solutions there that could be adapted for buses?

The elements in the problem description provided by TØI have been covered by a desk study conducted by IDIADA, which consists of the following elements:

1) Background
2) Accidentology review (2017; 2021; 2022)
3) Crash energy estimation (BUS-BUS)
4) Crash energy estimation (BUS-CAR)
5) Bus regulations for passive safety
6) Truck regulations
7) Proposal of front crash tests applied to buses
8) Proposal of structural improvements
9) Next stage of the investigation

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